

## **General Disclaimer**

### **One or more of the Following Statements may affect this Document**

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

(NASA-CR-167898) DEVELOPMENT AND TEST FUEL  
CELL POWERED ON-SITE INTEGRATED TOTAL ENERGY  
SYSTEMS. PHASE 3: FULL-SCALE POWER PLANT  
DEVELOPMENT Quarterly Report, Nov. 1981 -  
Jan. 1982 (Engelhard Industries, Inc.) 61 p G3/44 28648

182-30705

HC A04

Unclass

DOE/NASA/0241-4

NASA CR-167898



DEVELOP AND TEST FUEL CELL POWERED  
ON-SITE INTEGRATED TOTAL ENERGY SYSTEMS:  
PHASE III, FULL-SCALE POWER PLANT DEVELOPMENT

4TH QUARTERLY REPORT: NOVEMBER, 1981 - JANUARY, 1982

ENGELHARD INDUSTRIES DIVISION  
ENGELHARD CORPORATION  
EDISON, NJ 08818  
A. Kaufman, Contract Manager  
G. K. Johnson, Contract Technical Coordinator

REPORT DATE: June 21, 1982

PREPARED FOR  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
LEWIS RESEARCH CENTER  
UNDER CONTRACT DEN3-241

for  
U.S. DEPARTMENT OF ENERGY  
ENERGY TECHNOLOGY  
DIVISION OF FOSSIL FUEL UTILIZATION  
UNDER INTERAGENCY AGREEMENT DE-AI-01-80ET17088

DOE/NASA/0241-4  
NASA CR-167898

DEVELOP AND TEST FUEL CELL POWERED  
ON-SITE INTEGRATED TOTAL ENERGY SYSTEMS:  
PHASE III, FULL-SCALE POWER PLANT DEVELOPMENT

4TH QUARTERLY REPORT: NOVEMBER, 1981 - JANUARY, 1982

ENGELHARD INDUSTRIES DIVISION  
ENGELHARD CORPORATION  
EDISON, NJ 08818  
A. Kaufman, Contract Manager  
G. K. Johnson, Contract Technical Coordinator

REPORT DATE: June 21, 1982

PREPARED FOR  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
LEWIS RESEARCH CENTER  
UNDER CONTRACT DEN3-241

for  
U.S. DEPARTMENT OF ENERGY  
ENERGY TECHNOLOGY  
DIVISION OF FOSSIL FUEL UTILIZATION  
UNDER INTERAGENCY AGREEMENT DE-AI-01-80ET17088

## SECTION I. INTRODUCTION

Engelhard's objective under the present contract is to contribute substantially to the national fuel conservation program by developing a commercially viable and cost-effective phosphoric acid fuel cell powered on-site integrated energy system (OS/IES). The fuel cell offers energy efficiencies in the range of 35-40% of the higher heating value of available fuels in the form of electrical energy. In addition, by utilizing the thermal energy generated for heating, ventilating and air-conditioning (HVAC), a fuel cell OS/IES could provide total energy efficiencies in the neighborhood of 80%. Also, the Engelhard fuel cell OS/IES, which is the objective of the present program, offers the important incentive of replacing imported oil with domestically produced methanol, including coal-derived methanol.

Engelhard has successfully completed the first two phases of a five-phase program. The next three phases entail an integration of the fuel cell system into a total energy system for multi-family residential and commercial buildings. The mandate of Phase III is to develop a full scale 50kW breadboard power plant module and to identify a suitable type of application site. Toward this end, an initial objective in Phase III is to complete the integration and testing of the 5kW system whose components were developed during Phase II. Following the test of this sub-scale system, scale-up activities will be implemented as a total effort. Throughout this design and engineering program, continuing technology support activity will be maintained to assure that performance, reliability, and cost objectives are attained.

**SECTION II. TECHNICAL PROGRESS SUMMARY****TASK I - 5kW POWER SYSTEM DEVELOPMENT (97046)**

This task is of limited duration and has as its objective the complete integration of 5kW components developed during Phase II. This integrated 5kW system is automated under microprocessor control.

Most operating features of this system have been successfully checked out, as described in the Quarterly Report for August-October, 1981. Since that time a sub-stack voltage scanning capability has been added to the control system and tested for proper operation. An endurance system test at full load will be deferred until the stack is rebuilt in early 1982. Pfizer is producing ABA plates using improved technology for this rebuild. Small test pieces submitted by Pfizer based upon this technology have had satisfactory conductivity and edge-seal capability.

**TASK II - ON-SITE SYSTEM APPLICATION ANALYSIS (97047)**

The purpose of this task is to develop an application model for on-site integrated energy systems, with some emphasis on a system of 50kW (electrical) modular capability. The model will consider fuel availability and costs, building types and sizes, power distribution requirements (electrical and thermal), waste heat utilization potential, types of ownership of the OS/IES, and grid connection vs. stand-alone operation. The work of this task is being carried out under sub-contract by Arthur D. Little, Inc.

The major conclusions from A. D. Little's analysis to date are:

- Fuel cell OS/IES economics are relatively attractive under Con Edison rate structures.

**SECTION II. - CONTINUED**

- Centrifugal chiller-based systems with a fuel cell system that is small with respect to the electrical load yield a higher return on investment than absorption-chiller-based systems with a higher ratio of fuel cell capacity to electrical load. However, total savings potential is greater for the latter option.
- Fuel cell OS/IES are operated for best rate of return on investment as base-load rather than peak-load systems. For maximum savings potential, an intermediate-load design appears preferable.
- Methanol-based systems appear to have substantially lower rates of return than methane systems, based on today's price projections.
- Electric utility rate structures are probably more important in determining rate of return than are building loads and climate conditions. These latter variables are likely to affect optimum percentage of load met by the OS/IES.
- Target building types for further analysis are:
  - Hospital
  - Office
  - Apartment/dormitory
  - Retail store

Some background and details of these conclusions are given below.

## **SECTION II. - CONTINUED**

The basic scope of the A.D.L. project is to determine the market potential for fuel cell-based OS/IES by examining their cost and performance in representative building types, climate zones and electric utility rate structures. To be recommended is a test site or sites based on the economic and market analysis.

The approach includes four basic steps:

- Assembly of building and energy statistics
- Analysis of fuel cell OS/IES economics in selected applications
- Determination of market size and potential
- Recommendation of test sites

To date, data on buildings and building energy consumption have been collected and an operating analysis of a fuel cell OS/IES in a retail store with electric utility grid connection has been conducted.

On a preliminary basis, it appears that electric utility rate structures will be the key element in determining economic attractiveness of OS/IES. Building load profiles, the building type, and climate zone dependent variables are likely to affect the size of the OS/IES rather than its inherent operating economics.

As the next step, a full economic analysis is proposed of:

- One building type in multiple climate zones,
- Four building types in one climate zone, and
- Multiple electric rate structures on one or two building types.

**SECTION II. - CONTINUED****OS/IES OPERATION ANALYSIS**

In an earlier contract to NASA/Lewis, Arthur D. Little developed a model to determine:

- Necessary fuel cell OS/IES capacity and operating characteristics,
- Cost of a building's HVAC system with and without OS/IES, and
- Return on investment from a fuel cell OS/IES.

This earlier model assumed a stand-alone system; i.e., a building without connection to the electric utility grid structure. With the passage of the Public Utilities Regulatory Policy Act (PURPA) and the growing interest in cogeneration, the absence of electric utility grid connection appears to be overly restrictive and detracts from OS/IES market potential. Consequently, A.D.L. modified its model to accept grid connection, allowing the building to both purchase and sell electricity.

In order to test its modified model and to provide consistent information on OS/IES performance, A.D.L. conducted its first analysis on the retail store originally analyzed in the earlier NASA/Lewis work. This is a 112,000 square foot retail store (Table I), a size typical of moderate department stores. A.D.L. also assumed climate characteristics based on the earlier Washington, D.C. location.

The HVAC system and building loads for the base-case building are typical of buildings of that size and location. The HVAC system is an electric centrifugal chilled-water system for cooling and a hot-water boiler for heating. This is a slightly more sophisticated and costly system than might ordinarily be found in such a building, which biases the analysis slightly in favor of OS/IES.



**SECTION II. - CONTINUED**

The operating analysis consists of six elements to determine the:

- Capital cost of HVAC systems for the base-case building,
- Capital costs for fuel cell OS/IES and associated modifications of the HVAC system,
- Energy and other operating costs for the base-case systems,
- Energy and other operating costs for fuel cell OS/IES,
- Incremental costs and savings for fuel cell OS/IES alternatives, and
- Return on investment for fuel cell OS/IES

A.D.L. has, so far, conducted an operating analysis for fourteen basic OS/IES systems, using different numbers of fuel cell stacks and different combinations of heat (absorption) and electric (centrifugal) driven cooling systems.

In order to estimate the operating and energy costs for the fuel cell OS/IES, A.D.L. developed an operating strategy subject to basic constraints. The fuel cell OS/IES must meet the requirements of the Public Utilities Regulatory Policy Act (PURPA) which sets the conditions for qualified cogenerators. (Qualifications were set forth in the Quarterly Report for August-October, 1981.) This, basically, states that the OS/IES, or other cogenerator, must annually use on-site a certain portion of the energy not consumed in generating electricity. For the retail store, and most other buildings in reasonably northern climates, this is not a problem during the winter, when space heating requirements are high, but this constraint can be a problem in the summer.

## **SECTION II. - CONTINUED**

For buildings with electrical air-conditioning, the cogeneration rules place a limit on the total operating hours which can be achieved with a fuel cell OS/IES in the summer because demands for the waste heat do not equal electricity needs. In buildings with electric air-conditioners, the waste heat from the fuel cell OS/IES basically must be used to heat domestic hot water, and the summer domestic hot-water load serves as the limit on operating time for the fuel cell OS/IES. The PURPA cogeneration limitations can be overcome by substituting heat-activated air-conditioners, typically absorption chillers, for the electric air-conditioners. This substitution allows the fuel cell OS/IES to operate for more annual hours. However, absorption chillers are relatively inefficient and quite costly to operate when directly fired by fossil fuels. Consequently, it is desirable not to operate absorption chillers except with waste heat.

In addition to consistency with PURPA cogeneration requirements, fuel cell OS/IES systems were constrained to maximize the rate of return on the building owner's investment. In some instances, this tends to limit the size or operating schedule in ways that would not be preferred by the electric utilities. Utilities might prefer using a fuel cell OS/IES solely as a load-control device, operating only during peak periods. The building owner, however, prefers base-load fuel cell OS/IES operation.

In conducting this analysis, A.D.L. made basic assumptions on two key issues:

- Fuel cell OS/IES cost, and
- Fuel prices

A.D.L. assumed an installed cost of \$1,173 per kW (1980 dollars) for the fuel cell OS/IES. A.D.L. derived this cost from review of all

**SECTION II. - CONTINUED**

cost estimates available for phosphoric acid fuel cell systems over all size ranges.

For fuel costs, a consistent series of estimates has been used. Electricity costs are based on estimates of PURPA electricity rates for the Consolidated Edison Company, adjusted for consistency on oil-cost escalation. Natural gas prices are assumed to equilibrate with #6 heavy oil on a cost-per-BTU basis in 1985. For 1985 on, natural gas prices are predicted to increase with the price of oil as projected by the U.S. Department of Energy, Energy Information Agency. Methanol costs were developed based on coal-source methanol plants and Arthur D. Little, Inc. estimates (Table II).

The economic analysis begins in 1985, the earliest year for practical fuel cell OS/IES availability, and is conducted in constant 1980 dollars.

**PRELIMINARY ECONOMIC CONCLUSIONS**

Based on the analysis to date, the fuel cell OS/IES has its best rate of return on the building owner's investment:

- Operating as a base-load electricity generator
- In conjunction with centrifugal chillers
- Sized to operate at virtually 100% utilization

Under these conditions, a fuel cell OS/IES using one 50kW fuel cell module (Case Centrifugal Chiller 4) in the retail store using Consolidated Edison electric rates and natural gas has a constant dollar, post-tax rate of return of approximately 39% (Tables III and IV). Adding one more 50kW fuel cell module (Case Centrifugal Chiller 2) lowers the rate of return

## SECTION II. - CONTINUED

to 28% compared to the base-case building and gives an incremental rate of return of 20% compared to the one-module case. Adding three more modules (increasing to five 50kW modules, Centrifugal Chiller Case 1) still yields an incremental return of 20%. By most conventional investment criteria, this is still an attractive constant-dollar rate of return. While it is still too early in this study to draw conclusions on market potential, fuel cell OS/IES systems do seem attractive to the building owner under the assumed conditions. A major goal of the remaining study is to ascertain the sensitivity of these results to other assumptions.

Certain other observations are also possible at this stage. The first is that substituting absorption air-conditioners for electric ones allows for greater utilization of fuel cell waste heat, but substantially cuts the rate of return. The best return for an absorption chiller system is in a ten-module system and is 16% relative to the base case. This system, however, has a 5% return versus the next nearest centrifugal-chiller option. The detailed reasons for this have not been fully analyzed, but it appears that the extra capital cost of the absorption chiller cannot be effectively recouped from fuel savings. However, consideration of day/night thermal storage and chiller integration with the fuel cell system could substantially alter these results.

The analysis so far indicates that building type, load profile, and climate zone, all interrelated variables, will affect the size (in kW per square foot of building) of the fuel cell OS/IES. Electric utility rate structures are likely to affect the absolute value of the rate of return. All variables will be tested in further analysis, with concentration on electric rate issues.

**SECTION II. - CONTINUED****BUILDING TYPE SELECTION**

Beyond determining operating parameters and user economics of a fuel cell OS/IES, A.D.L. has also analyzed the electrical/thermal match between fuel cell OS/IES and various building types, leading to a determination of fuel cell OS/IES market potential and to a recommendation of a demonstration building type. The determination of appropriate building types includes a variety of considerations:

- Typical energy load profile,
- New construction volume and existing stock,
- Adaptability of design process, and
- Receptivity of owners

On the basis of all four of these considerations, A.D.L. recommends and plans to conduct further analysis on four broad building types:

- Hospitals
- Offices
- Dormitories/apartments
- Retail stores

The best operating performance, based on return on investment, and the maximum attractive size, in kW per square foot of building, appear to be obtained in buildings with a high non-seasonal heat load compared to the peak electric load. For virtually all building types, this translates into a preference for large hot-water loads (non-seasonal) relative to the air-conditioning (seasonal) loads, and a high ratio of hot-water energy demand to air-conditioning energy

**SECTION II. - CONTINUED**

demand provides a useful figure-of-merit as one step in assessing appropriateness of buildings for fuel-cell-based OS/IES.

Based on the ratio of hot-water demand to hot-water plus air-conditioning (Table V), apartments have the most suitable load profiles, followed by hospitals. At the opposite extreme, retail stores with high air-conditioning demand plus low hot-water needs have load profiles less suited to the use of cogeneration systems.

Load profiles are not the only determinant of attractiveness of building types as users of fuel cell OS/IES. The number of available buildings and the ease of adaptation also will be key influences. Ease of adaptation is dependent on the first-cost sensitivity of the building owner and on the ability to successfully incorporate the fuel cell OS/IES into the building design process. A.D.L. has ranked building types by first-cost sensitivity of their owners (Table VI) based on background knowledge of the building industry, where an "A" implies low first-cost sensitivity. On this basis, government, institutional and other publicly-owned buildings are favored as are owner-occupied offices. Speculative or leased buildings are not favored.

A.D.L. has also identified the presence of field-engineered HVAC systems as a route to designing and incorporating a fuel cell OS/IES into the building. Buildings with simple, roof-top or unitary air-conditioners are not typically designed by engineers capable of integrating a fuel cell OS/IES. Conversely, buildings which use field-engineered air conditioners (large chillers) have sophisticated engineers who can integrate the fuel cell OS/IES. Offices, industrial buildings, and health-care facilities have a high penetration of field-engineered air-conditioners and are, thus, prime markets on this

## **SECTION II. - CONTINUED**

criterion for fuel cell OS/IES (Figure 1). Office buildings also have the largest total number of square feet of new construction using field-engineered HVAC equipment, making it a relatively more attractive market (Table VII). Interestingly, retail stores also have a large number of square feet of field-engineered HVAC equipment because that building end use is a large portion of the total area of new nonresidential buildings.

Further analysis of four building types is suggested:

- Hospitals, because of attractive load characteristics
- Offices, because of the size of the field-engineered HVAC market
- Apartments, because of attractive load characteristics
- Retail stores, because of total market size

### **TASK III - ON-SITE SYSTEM DEVELOPMENT**

This task forms the core of the Phase III Contract. Work under this task will result in the breadboard design of a system for an on-site application. The power plant will be designed for a rated output of 50kW (electrical) or some multiple thereof. The fuel processor and power conditioner will each be 50kW modules, while the 50kW fuel cell will comprise two 25kW stack modules. This task is accordingly broken down into four sub-tasks as follows:

- 3.1 Large Stack Development (97048)
- 3.2 Large Fuel Processor Development (97038)
- 3.3 Overall System Analysis (97051)
- 3.4 Overall System Design and Development (97064)

# **ENGELHARD**

## **SECTION II. - CONTINUED**

A large part of Sub-Task 3.3 is being carried out by Physical Sciences Inc. (PSI) under subcontract.

### **LARGE STACK DEVELOPMENT (97048)**

The variable-stack test fixture for full-sized cells (0.33 x 0.56 m, 13" x 22") was described in the Quarterly Report for August-October, 1981. The fixture has been completely fabricated and Teflon-coated by an outside vendor. Handling facilities and test station for this unit are currently being readied. The fixture will accommodate any number of full-sized cells from one to twenty-four. The first test in the unit will be a single-cell test, anticipated to begin in March.

A design for a full-sized metallic cooling plate has been submitted to a vendor for fabrication; these plates will be needed for the first 24-cell test, scheduled for May.

A-elements (grooved needled-felt) and electrodes for the single-cell test have already been completed. The cathode catalyst for this cell is of the stabilized-Pt/stabilized-support type containing 10% Pt. Its original Pt surface-area is 86 m<sup>2</sup>/g. This catalyst is formulated with Teflon (TFE, Type 30) such that the final mix is 50% polymer. The anode catalyst is of the Pt-only type (10%) and has an initial Pt surface-area averaging 100 m<sup>2</sup>/g. It is formulated such that the final mix is 45% fluorocarbon polymer. The matrix for both electrodes is of the silicon carbide paste type.



# ENGELHARD

## SECTION II. - CONTINUED

### LARGE FUEL PROCESSOR DEVELOPMENT (97038)

Recent emphasis in the design of a 50kW fuel processor has shifted away from a custom approach and toward the use of off-the-shelf shell-and-tube heat exchangers. The Perry Products Corporation of Hainesport, N.J. has been selected as the vendor for suitable units for this program. Their standard exchangers are constructed of 316 stainless steel.

A 5 kW-equivalent unit will be procured first as a sub-scale unit for testing the concept. Data from this test program will be used to specify optimum baffle spacing for a 50 kW-equivalent unit. Quoted data on these two units are as follows:

<u>Tube Surface Area</u>	<u>kW-Equivalent</u>	<u>Shell Diameter</u>	<u>Overall Length</u>	<u>Price (One Unit)</u>
1.2m <sup>2</sup> (13 ft <sup>2</sup> )	5	15cm (6")	1.7m (5.5')	~\$ 4,875
11.8m <sup>2</sup> (126 ft <sup>2</sup> )	50	41cm (16")	1.8m (6')	~\$10,700

### OVERALL SYSTEM ANALYSIS (97051)

Work is proceeding at Physical Sciences Inc. on development of off-design modules to be used in predicting and controlling behavior of the system at less-than-design-load operation. This work is nearly complete and the program package is scheduled to be delivered to Engelhard in May.

Previous program packages developed by PSI on stack, reformer and HVAC subsystems were translated from BASIC to FORTRAN and are installed and operational in the Engelhard PDP 11/34 system.

# **ENGELHARD**

## **SECTION II. - CONTINUED**

### OVERALL SYSTEM DESIGN AND DEVELOPMENT (97064)

PSI has prepared the basic tools for a computer analysis of a novel air-conditioning concept (See Appendix to Quarterly Report of February - April, 1981). Following some modifications of PSI's assumptions, Engelhard's computer group has devised a program for the thermodynamic analysis of the concept. This program is now being run with a variety of assumptions regarding parameter values. The key output variable to be calculated is the coefficient of performance (C.O.P.); i.e., the ratio of useful air-conditioning and heating output to total thermal and electrical input.

Heat-of-fusion materials are still being considered for day/night condenser cooling storage. A new paraffin sample from Compounders, Inc. has a melting range around 290 K and is being evaluated. Its function would be to provide a relatively cool condensing temperature for absorption chillers used in the HVAC, thus improving their C.O.P. and cooling capacity.

### TASK IV - STACK SUPPORT (97049)

The purpose of this task, which will continue throughout the contract, is to investigate new materials and component concepts by experimentation and the use of small-stack trials. The criteria for choosing activities under this task will be the possibilities of improved performance or reduced cost, or both. Improvements in and performances of electrocatalysts, though generated under Engelhard-sponsored Task VI, will be reported under Task IV.

## SECTION II. - CONTINUED

CARBON-MONOXIDE POISONING

Cyclic-voltammetry has been employed to investigate the effect of CO on the hydrogen oxidation reaction. Figure 2 shows typical voltammograms for a 10 wt % Pt on carbon ( $0.45 \text{ mg/cm}^2$ ) electrocatalyst in 25%  $\text{H}_3\text{PO}_4$  at  $25^\circ\text{C}$ , saturated with  $\text{H}_2$  and 5%  $\text{CO/H}_2$ , respectively. The oxidizing current in Sweep 3 beginning around 0.6 V is due to the removal of adsorbed CO as  $\text{CO}_2$ . Integration of appropriate areas under these curves shows that the reduction in hydrogen adsorption charge is quantitatively related to the portion of the electrocatalyst surface occupied by carbon monoxide. Hence, the hydrogen adsorption charge retention in the presence of carbon monoxide serves as a measure of carbon-monoxide tolerance.

Hydrogen adsorption charge at  $25^\circ\text{C}$  in the presence of 5%  $\text{CO/H}_2$  and hydrogen-gain\* measurements obtained from typical fuel cell performance tests have been studied for various catalysts. Figure 3 indicates that catalysts with high hydrogen adsorption charge (high platinum surface-area retention) show superior carbon-monoxide tolerance (low hydrogen-gain).

An observation of additional interest, shown in Figure 4, is the correlation between the platinum surface-area of the catalyst and the amount of time required to saturate the catalyst surfaces with CO (while exposed to 100% CO).

---

\* Hydrogen-gain: Fuel cell voltage gain (at  $161 \text{ mA/cm}^2$ ,  $190^\circ\text{C}$ ) when changing the fuel from reformat (65%  $\text{H}_2$ , 23%  $\text{CO}_2$ , 10%  $\text{H}_2\text{O}$ , 2% CO) to pure hydrogen.

## SECTION II. - CONTINUED

CORROSION STABILITY OF CARBON SUPPORTS

A screening and monitoring program is maintained in which existing and candidate carbon supports for catalysts are tested for the magnitude of their corrosion currents at 1.0 V. The test is more severe than conditions met in actual service. The reason for conducting this screening test is the possibility of long-term attrition of support material in service and attendant loss of precious metal.

Typical short-term data from this test are shown for several types of support in Figure 5. Longer-term data are also obtained and will be presented at a later time.

BIPOLAR PLATE DEVELOPMENT

Work during this quarter in bipolar plate development and construction consisted of the following activities:

1. Development of an improved ABA bonding technique.
2. Manufacture of 1 ft<sup>2</sup> plates for the rebuild of the 5 kW stack.
3. Manufacture of 2 ft<sup>2</sup> A-elements for full-size single-cell test (0.33 x 0.56 m, 13" x 22").
4. Fabrication of prototype ABA plates in 2 ft<sup>2</sup> size.
5. Final set-up and check-out of the grooving machine for grooving of both 1 ft<sup>2</sup> and 2 ft<sup>2</sup> plates.

These items are discussed individually below:

Earlier ABA plates bonded with graphite adhesive exhibited variations in electrical conductivity and thickness due to corrugations

# ENGELHARD

## SECTION II. - CONTINUED

and lack of compaction in the bond layers between the A-elements and the B-elements. These conditions were corrected by incorporating the following steps into the bonding procedure:

1. A-elements are pre-sealed by applying a thin layer of adhesive to the bonding surface and curing.
2. Bonding adhesive is applied to the A-elements in a uniform thickness by a modified doctor blade method.
3. The three elements are pressed together at a pressure of 70-140 kPa (10-20 psig) prior to curing.
4. During curing the elements are held in contact in a clamping fixture.
5. The cured ABA plate is heat-treated at 1100°C to carbonize all of the cured adhesive.

Seventy-two 1 ft<sup>2</sup> ABA bipolar plates were manufactured by Pfizer using the sequence outlined above. In addition, 48 A-elements were produced. This set of A and ABA plates, after grooving and edge-sealing, will be used to rebuild the 5 kW stack.

Twenty 2 ft<sup>2</sup> plates were CVD'ed to approximately 75% of final density. Four of these plates were used to fabricate prototype 2 ft<sup>2</sup> ABA plates. The balance were further CVD'ed for use in a full-size single-cell test and in machining trials.

The two 2 ft<sup>2</sup> ABA prototype plates were made using the bonding sequence above. The purpose of this fabrication was to determine whether any warpage or other dimensional problems would

# ENGELHARD

## SECTION II. - CONTINUED

result due to the larger size of the plate or due to the furnace fixturing used. No such difficulties were encountered.

The grooving machine was checked for proper operation by grooving a lot of 100 plates for an Engelhard-sponsored project. Cutting arbors have been assembled for the larger 2 ft<sup>2</sup> plate size for the NASA program. Initial grooving trials on the full-size plates will be conducted in early February.

### CORROSION BEHAVIOR OF GRAPHITE ADHESIVE

Tests on small sections of completed ABA plates were performed in concentrated H<sub>3</sub>PO<sub>4</sub> at 204°C at a potential of 0.9 V vs. the reversible hydrogen electrode. As-received ABA plate sections (adhesive heat-treated at 1100°C) showed relatively high corrosion currents. Tests on samples of the individual A and B components showed that the high currents were sustained in the graphite adhesive layer and not in the A or B elements themselves. (See the upper curve in Figure 6.)

In order to improve the corrosion resistance of the bonding adhesive layer two approaches were tried: 1) Heat treatment of the ABA plate at higher temperatures to further graphitize the adhesive, and 2) Application of additional CVD to coat the graphite adhesive layer. Figure 6 shows the corrosion currents as a function of time for samples heat-treated at 1100°C, 1700°C and 2400°C. It is seen that corrosion currents were significantly reduced as heat-treatment temperatures were elevated. For these tests, the ABA plate samples were split apart and the adhesive only, attached to the B-element, was subjected to test.

**SECTION II. - CONTINUED**

The effects on corrosion of adding an additional CVD layer on top of 1100°C heat-treated adhesive are shown in Figure 7. It is shown that the CVD layer reduces the corrosion of the adhesive layer by about two orders of magnitude.

It is planned to check whether corrosion products from this adhesive layer, when they enter the electrolyte, become surface poisons for catalysts. This test will be done by cyclic-voltammetry.

**ELECTRICAL MEASUREMENTS**

A series of resistance measurements on plates made of needled-felt, Fiberform carbon, reticulated vitreous carbon (RVC) and graphite/polyethersulfone (PES) composites shows that, for plate thicknesses less than 1 cm, the major resistive contribution (at least 80%) occurs at the pressure contact interfaces (i.e., at surfaces that are neither glued nor otherwise permanently bonded). Nevertheless, at any given pressure and surface flatness condition, the contact resistance is roughly proportional to the bulk conductivity of the plate material.

It has become evident that standard methods for measuring the electrical resistance of ABA plates, cooling plates, and contacts to and between such plates do not yield reliable and repeatable results. The problem stems from unavoidable variations in the bulk and contact resistivities of the plates. Such local variations generate skewed conduction paths which do not fit the model of parallel current paths on which the standard 4-probe measurement techniques are based. This problem has been solved by making two basic changes in the measuring technique.

**SECTION II. - CONTINUED**

Gold-plated copper screens are used as the outer contacting surfaces with Grafoil sheets in direct contact with those screens. The screens provide an equipotential surface that averages out the effects of skewed conduction paths, while the Grafoil sheets supply high quality contacts between the screen surface and that of the sample to be measured.

The other change is the use of a substitution method. The resistance from screen to screen is measured with and without the component or components whose resistance is to be determined, and the result of one measurement is subtracted from that of the other. Since these changes were made, plate and interface resistance measurements have become consistently accurate and reproducible.

The method described above has yielded the following typical voltage drops at  $161 \text{ mA/cm}^2$  and at pressures of 345 kPa (50 psig):

Needled-felt ABA plates ( $1 \text{ ft}^2$ , ungrooved):	2.9 mV/3mm
RVC plates (ungrooved):	2.3 mV/3mm
Fiberform carbon, cooling plate pair; cold:	22 mV/3mm
670 K:	15 mV

**NICKEL-PHOSPHOROUS COATING FOR METALLIC COOLING PLATES**

This coating was recommended by the National Bureau of Standards as being possibly resistant to chemical attack by  $\text{H}_3\text{PO}_4$  at 470 K (fuel cell temperature). Corrosion tests of an NBS-supplied sample of the coating about 0.5 mm thick showed a weight loss of 58% in 800 hours when submerged in 100% phosphoric acid at 280 K. This kind of coating is thus ruled out for cooling plate protection.



## SECTION II. - CONTINUED

CORROSION OF FIBERFORM CARBON

Fiberform carbon, a partially resin-based carbon material with possible uses in fuel cell plates, was tested at various anodic potentials in phosphoric acid at 280 K. The following table shows the initial corrosion currents on Fiberform carbon compared to those on needled-felt:

<u>Anodic Potential, V</u>	<u>Corrosion Currents, mA/cm<sup>2</sup></u>	
	<u>Fiberform</u>	<u>Needled-Felt</u>
0.7	0.009	0.007
0.8	0.025	0.007
0.9	0.113	0.008

The data show that Fiberform corrodes much faster than needled-felt. A contributing factor is likely to be the much greater pore surface-area of the former. Through chemical vapor deposition (CVD) of additional carbon it may be possible to upgrade Fiberform by plugging a large percentage of its open pores.

GRAPHITE/POLYETHERSULPHONE (PES) COMPOSITES

For these potential plate materials, the contact resistance is adversely affected by the tendency of the PES sealant to smear over the plate surface, forming a high resistance film. A way to sand off this film has been devised. It entails blowing off the abraded surface material rapidly while sanding takes place. IR drops in the range of 3-10 mV have been achieved at 161 mA/cm<sup>2</sup> and 345 kPa (50 psig) following this procedure.

## SECTION II. - CONTINUED

ACID MANAGEMENT

Two 3-cell stacks which are equipped with semi-automatic electrolyte management systems have been on long-term test. The components of both these stacks have been described in previous reports.

An updated performance for the first of these stacks (#11483-1) is given in Figures 8-10. The total duration of testing so far is 6000 hours. Figure 8 shows the history of the open-circuit voltage, which is a good measure of the effectiveness of electrolyte management. Figure 9 gives the voltage at standard load current ( $161 \text{ mA/cm}^2$ ). This stack also incorporates an advanced cathode catalyst in two cells. Figure 10 shows individual cell performances and indicates that the cells with the advanced catalyst have given the highest voltages.

A second 3-cell stack with a more advanced electrolyte-replenishment system has been run for 3400 hours. Its performance history is shown in Figure 11 (open-circuit voltage) and Figure 12 (voltage under load). A feature to be noted is the very flat and steady behavior of the open-circuit voltage, indicating excellent acid management.

TASK V - FUEL PROCESSING SUPPORT (97050)

The intent of this task is to provide background data and information to support the design and construction of an optimized 50kW fuel processor under Task III. This support function will continue throughout most of the period of the contract. Most of the effort of this task is devoted to screening and longevity testing of catalysts for methanol/steam reforming.

## SECTION II. - CONTINUED

CATALYST TESTING

The ethanol-poisoning tolerance test on methanol/steam reforming catalyst C70-2RS (zinc/chromium oxides) continued to 2750 hours. During the last 750 hours the catalyst was exposed to ethanol contaminant (800 ppm) with no sign of deactivation at 670 K. The weight-hourly-space-velocity was 0.60 and methanol conversion was near 100%. Results of the last portion of the run are shown in Table VIII, which is a continuation of Table III of the Quarterly Report for August-October, 1981.

The conversion data for the entire test are plotted in Figure 13. At 1144 hrs., addition of 800 ppm ethanol decreased methanol conversion from 85 to 74% when operating at 640 K. Returning to uncontaminated feed at 1575 hrs, the conversion recovered to 85% (Actually, as shown in Figure 13, recovery started during the ethanol contamination period.) Returning again to ethanol contamination at 1968 hrs, approximately 100% conversion was achieved at 670 K with no decline noted over a period of about 750 hours.

Figure 14 is offered for comparison of C70-2RS with T2107RS catalyst (zinc/copper oxides). In Figure 14 the copper-zinc catalyst did not recover to initial conversion (85%) after contamination and return to clean feed. Higher operating temperatures could not be employed with this catalyst because it deactivates above 543 K.

In conclusion, C70-2RS catalyst has been shown to be much more resistant to contamination than T2107RS. Although the former is less active than the latter, compensation can be attained by operating at higher temperatures. Higher temperature operation seems desirable for contaminated feeds. The Cr/Zn catalyst has the needed stability to operate at these high temperatures, yet produces an acceptable level of CO (about 2.5%).

## SECTION 11. - CONTINUED

SINGLE-TUBE STUDIES

Radial profiles have been measured in a 2" diameter tubular reactor heated by gas flowing in the annulus. The results are being compared with those predicted by the two-dimensional model. Calculations have shown radial temperature gradients in excess of 50°F for tubes 2" in diameter. A key parameter in these calculations is  $H_w$ , the heat transfer coefficient at the wall. Since the estimation of  $H_w$  is not straightforward, experimental data are required to select an appropriate value of  $H_w$ .

The experimental set-up is shown in Figure 15 where catalyst is contained in a 2" diameter tube. The outer shell is a 3" diameter tube and flue gas flows in the annulus. Prevaporized and superheated process gas ( $\text{MeOH}/\text{H}_2\text{O}$ ) enters the reactor through a flared section which serves to distribute the gases uniformly across the 2" bed.

Preliminary studies with inert packing had shown unusual radial profiles at the 10.2 cm position. This was possibly due to entrance effects. The set of thermocouples at the 39.4 cm position gave a smooth profile of the expected magnitude. Therefore, catalyst was loaded into a zone centered about this middle set of thermocouples, with inert packing above and below the catalyst zone.

Heating tape on the outside of the shell prevented heat-loss to the outside. Air was used to simulate flue gas and this was metered to give the same mass flow rate as flue gas in the actual reactor. This air was preheated before entering the reactor shell.

The results from two runs are presented to illustrate the type of data obtained with this equipment. In both runs, 1100 ml/hr of methanol/water mix ( $1.3 \text{ H}_2\text{O}/\text{CH}_3\text{OH}$ ) was fed to the unit containing

## SECTION II. - CONTINUED

259 g of T2107RS (Cu/Zn) catalyst. The WHSV\* in both cases was 1.90g/hr/g catalyst. The condensate was collected and analyzed for  $\text{CH}_3\text{OH}$  and  $\text{H}_2\text{O}$  by gas chromatography. The gas was measured for volumetric flow rate using a dry test meter and analyzed for  $\text{H}_2$ ,  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ , and  $\text{CH}_3\text{OH}$ .

Figure 16 shows the temperature profile obtained in Run 3ST. The flue gas (FG) temperature was essentially constant across the zone of the catalyst at about 640 K. The temperature dropped in the axial direction above the catalyst bed (due to axial heat conduction). The radial profile showed 66 K difference between the center-line and the wall. About 67% methanol conversion was observed with an average bed temperature of 493 K (428°F).

In Run 4ST (Figure 17) the flue-gas temperature was lowered to about 489 K by cutting back on the power to the heating tapes. The radial temperature difference was only 22 K. Methanol conversion was 28% at an average bed temperature of 467 K (381°F).

Figure 18 summarizes the results of these two runs. The very steep radial profile of Run 3ST results from the high wall temperature and strong driving force between the flue gas and the tube wall. When this driving force is lowered as in Run 4ST, the radial gradient is lower. Note that in the two cases the temperatures at the center-line are nearly equivalent.

A comparison of average bed temperature and conversion level is as follows:

Run No.	<u>3ST</u>	<u>4ST</u>
Average Bed Temp, K	493	467
Methanol Conv., %	67	28

---

\* Weight-hourly space-velocity (g  $\text{CH}_3\text{OH}$ /g catalyst/hr)

# **ENGELHARD**

## **SECTION II. - CONTINUED**

The increase in conversion is as expected for a first-order reaction with an activation energy of 84 kJ/mole.

These two runs illustrate how radial temperature gradient changes with driving force (difference in temperature between flue gas and wall) and reaction rate (as shown by methanol conversion). Tests in progress at the same flue gas and inlet temperatures, but with ethanol added to the feed, will show the effect of changing catalyst activity on the radial temperature gradient. A test with C70-2RS, which is much less active, is also scheduled.

### **TASK VI - IMPROVED ELECTROCATALYSTS (97039)**

Developmental electrocatalyst formulations are being prepared under Engelhard sponsorship. These are provided to the main program, and results are reported under Task IV.

**ENGELHARD**

SECTION III. CURRENT PROBLEMS

NONE.

**SECTION IV. - WORK PLANNED****TASK I**

- A and ABA plates for 5 kW stack rebuild to be sized and grooved.

**TASK II**

- A. D. Little, Inc. to develop rate structure analysis of four utilities.

**TASK III**

- Test station to be readied for full-size single-cell test.
- Specifications to be completed for 5kW shell-and-tube reformer.

**TASK IV**

- Developmental work on non-metallic cooling plate and acid management system to continue.

**TASK V**

- Single-tube reformer study of C70-2RS to be completed.
- Catalyst selection for 50 kW processor to be made.



**SECTION V. FINANCIAL MANAGEMENT ANALYSIS****TASK I - 5kW POWER SYSTEM DEVELOPMENT**

Essentially no expenses were incurred during January. Activity was limited to Pfizer's preparation of new ABA bipolar plates for the 5kW stack.

**TASK II - ON-SITE SYSTEM APPLICATION ANALYSIS**

No expenditures by Arthur D. Little, Inc. are indicated during January because of late invoicing. Cumulative costs remain below projections. Roughly one-third of the funds have been expended.

**TASK III - ON-SITE SYSTEM DEVELOPMENT****1. Large Stack Development**

Expenditures on this sub-task were high in January as hardware development activities for large-area stacks remained substantial. Total labor expenditures to date are at the planned level. Materials expenditures are running somewhat ahead of the anticipated rate.

**2. Large Fuel Processor Development**

Costs for January were slightly below the projected amount. Cumulative expenditures remain about 15% below the plan.

**3. System Analysis**

No costs were sustained on this sub-task during January because of a subcontract invoicing lag. Effort at Physical Sciences Inc. is

# **ENGELHARD**

## **SECTION V. - CONTINUED**

being directed toward analysis of the system under off-design conditions. Total spending to date is slightly below the planned level.

### **4. System Integration**

A small amount of work was performed on this sub-task during January. Earlier, in-house effort on the HVAC sub-system was conducted to lay the groundwork for an anticipated subcontract. Accordingly, manpower expenditures remain above budget (by about 80% through January). However, overall costs are well below the projected level because of the lack of subcontract effort in 1981.

### **TASK IV - STACK SUPPORT**

The Pfizer subcontract for bipolar plate scale-up and cost reduction development began in January. However, invoicing has not yet been received. The rate of spending for this task is about one-third below projections.

### **TASK V - FUEL PROCESSING SUPPORT**

Sub-scale tests involving qualification of large batches of catalyst are near completion. Manpower requirements for these activities have been reduced from anticipated levels. Total expenditures, therefore, remain at roughly half of those projected.

### **TASK VI - IMPROVED ELECTROCATALYSTS**

The development of advanced anode and cathode catalysts is proceeding under Engelhard sponsorship. Evaluation of these catalysts is accomplished under Task IV.

# **ENGELHARD**

## **SECTION V. - CONTINUED**

### **TASK VII - MANAGEMENT AND DOCUMENTATION**

Expenditures in the management and documentation area are proceeding substantially according to plan.

**TABLE I****TEST BUILDING DESCRIPTION**

● Building Type - Retail Store	
● Size - Floor Area	112,000 ft <sup>2</sup>
Ceiling Height	10 ft
● Test Location - Washington, D.C.	
● Base Case HVAC System - Centrifugal Chillers Plus Boiler	
● Space Heating Load	7,900 Million Btu/Year
● Cooling Load	4,800 Million Btu/Year
● Hot Water Load	450 Million Btu/Year
● Non-HVAC Electrical Load	7,100 Million Btu/Year (2 Million kWh/year)
● Peak Heating Load	1.1 Million Btu/Hour
● Peak Cooling Load	4.1 Million Btu/Hour
● Peak Non-HVAC Electrical Load	1.6 Million Btu/Hour (470 kW)
● Peak Electric Load	2.9 Million Btu/Hour (850 kW)

Source: NASA/Lewis

TABLE IIENERGY COSTS - TEST ANALYSIS

(1980 Dollars)

	Electricity <sup>①</sup>		Gas <sup>②</sup>	Methanol
	OS/IES Buys	OS/IES Sells	(\$/MBtu)	(\$/MBtu)
1980	0.048	0.075	2.90	--
1985	0.082	0.138	8.20	18.13
1990	0.082	0.138	9.10	18.55
1995	0.096	0.164	10.22	18.76
2000	0.1076	0.184	12.38	19.04

Demand Charge: \$11.00/kW - Winter  
\$14.50/kW - Summer

① Based on rates projected for Consolidated Edison. Only lowest buying and highest selling rates are quoted. ADL is developing more complete information.

② Some corrections have been made in this column since this table first appeared in the November report.

Source: Arthur D. Little, Inc., estimates based on  
U.S. Department of Energy, Energy Information Agency.

TABLE III

## PRELIMINARY COMPARISON OF FUEL CELL OS/IES OPTIONS

## RETAIL STORE

Category	No of Fuel Cell Modules	Size of the Absorption Chiller (Tons)	Size of the Centrifugal Chiller (Tons)	Size of Thermal Storage (Gallons)	Yearly Electricity Generated (Million kwh)	Yearly Electricity Sold (Million kwh)	Yearly Electricity Purchased (Million kwh)	Yearly Gas Used (Million Btu)	Economic Ranking for All units
Absorption Chillers									
1	3	240	--	100,000	1.31	0.235	1.21	24,500	13
2	5	240	--	100,000	2.17	0.643	0.754	32,000	9
3	5	260	--	1,000	2.05	0.552	0.782	30,200	12
4	7	240	--	100,000	3.04	1.09	0.343	39,500	7
5	10	240	--	100,000	3.86	1.79	0.228	46,300	6
6	15	240	--	100,000	4.96	2.56	0.200	53,100	8
Centrifugal Chillers									
1	5	--	240	100,000	1.78	0.377	1.22	16,600	4
2	2	--	240	100,000	0.869	0.033	1.78	9,270	3
3	1	--	240	100,000	0.419	--	2.20	5,962	2
4	1	--	360	0	0.438	0.002	2.15	6,820	1
5	10	--	240	100,000	1.61	0.788	1.79	15,100	11
Centrifugal and Absorption Chillers									
1	5	120	120	100,000	2.17	0.614	0.798	30,000	10
2	5	25	215	100,000	2.17	0.509	0.909	22,200	5

\* Each fuel cell module is 50 kW.

**TABLE IV****ECONOMIC RANKING OF FUEL CELL OS/IES BASED ON NATURAL GAS****Rate of Return Versus:**

<b><u>System</u></b>	<b><u>Base Case</u></b>	<b><u>Previous Line OS/IES</u></b>
Centrifugal Chillers, 1 module	39%	Not applicable
Centrifugal Chillers, 2 modules	28%	20%
Centrifugal Chillers, 5 modules	25%	20%
Centrifugal & Absorption, 5 modules	20%	Negative
Absorption Chillers, 10 modules	16%	9%
Absorption Chillers, 7 modules	16%	Not applicable
" " , 15 modules	14%	12%
" " , 5 modules	12%	Not applicable
Centrifugal Chillers, 10 modules	10%	8%
Absorption Chillers, 3 modules	2%	Not applicable

TABLE VENERGY USE IN EXISTING NONRESIDENTIAL BUILDINGS

<u>Building Type</u>	<u>%AC</u>	<u>Hot Water (000 Btu/sq.ft./yr)</u>	<u>Air Conditioning (000 Btu/sq.ft./yr)</u>	<u>Hot Water + ( Hot Water + Air Conditioning ) %</u>
Offices	60	5.8	44.0	11.6
Retail	65	1.5	26.6	5.3
Health	60	31.8	107.7	23.0
Education	45	6.0	41.5	12.6
Apartments	50	14.5	14.2	50.5

Source: Arthur D. Little, Inc., estimates



TABLE VI

ON-SITE FUEL CELLSELIGIBLE MARKET BY BUILDING TYPES

<u>Building Type</u>	<u>Load Profile</u>	<u>HVAC System Complexity</u>	<u>Owner Occupied</u>	<u>Prime Market Size 1980</u>		<u>First Cost Sensitivity</u>	<u>Overall Ranking</u>	<u>Key Decision Maker</u>
				(000,000 Sq. Ft.) New (Annual)	Existing (Stock)			
Hospital & Health	A	A	A	56	1,268	A	A	Owner, Architect
Apartments	B	C	C	488	16,680	D	C	Developer, Contractor
Motel & Hotel	B	C	A	49	1,992	D	C	Owner
Inmitories	B	B	A	8	*	A	B	Architect, Engineer University
Stores & Mercantile	C	B	C	184	8,785	D	C	Developer, Contractor
Manufacturing	C	D	A	172	6,661	D	C	Owner
Laboratories	C	A	A	17	**	B	B	Owner, Engineer
Libraries & Other Government	C	B	A	18	***	A	B	Architect, Engineer
Amusement & Misc.	C	D	C	100	5,102	D	C	Contractor, Owner
Warehouses	D	D	C	227	6,028	D	B	Builder
Offices	D	B	B	244	7,277	C	C	Developer, Contractor
Garages	D	D	D	63	5,445	D	D	Owner
Government Offices & Schools	D	B	A	86	5,626	A	C	Architect, Engineer
Religious	D	D	A	29	****	B	C	Architect, Building Committee

3,124

Other

\*Included with schools

\*\*Included in others

\*\*\*Included with amusement &amp; other

\*\*\*\*Included with amusement

A - Favorable to fuel cell OS/IES

D - Unfavorable to fuel cell OS/IES

**TABLE VII****FIELD-ENGINEERED AIR CONDITIONING****NEW CONSTRUCTION - 1980  
(million square feet)**

<b><u>Building Type<sup>1</sup></u></b>	<b><u>Total</u></b>	<b><u>%</u></b>	<b><u>Field-Engineered</u></b>	<b><u>%</u></b>
Offices	261	21	141	40
Industrial	180	14	50	14
Retail	324	26	68	19
Health	56	4	31	9
Education	103	8	39	11
Lodging	49	4	4	1
Other	278	22	19	5
Total	1251	100	352	100

<sup>1</sup>Excludes apartments

Source: Arthur D. Little, Inc., estimates

TABLE VIIIMETHANOL/STEAM REFORMING CATALYST TEST

Water/Methanol Molar Feed Ratio = 1.3

Catalyst: UCI C70-2RS Zinc/chromium oxide  
1/8" x 1/8" Pellets  
10 cc in 90 cc alpha alumina,  
mixed logarithmically

(All data with 800 ppm ethanol in feed.)

<u>Hours on Stream</u>	<u>Avg. Bed Temp., K</u>	<u>Exit Bed Temp., K</u>	<u>% CO</u>	<u>% MeOH Conversion</u>	<u>WHSV*</u>
1968	674.2	655	2.41	99.45	0.60
2000	673.0	666	2.46	99.44	0.59
2133	669.3	663	2.46	95.2	0.59
2228	672.0	668	2.26	99.3	0.60
2300	672.3	665.6	2.33	99.46	0.60
- Shut down for ten hours -					
2420	672.8	672	1.70	98.9	0.60
- Shut down for seventy-six hours -					
2505	671.8	665.7	3.58	97.9	0.56
2554	672.2	679	2.86	100.0	0.56
2649	672	675	2.31	100.0	0.56
2721	671.0	677	2.54	100.0	0.61

\* Weight-Hourly Space-Velocity ( $\text{kgCH}_3\text{OH/hr kg catalyst}$ )

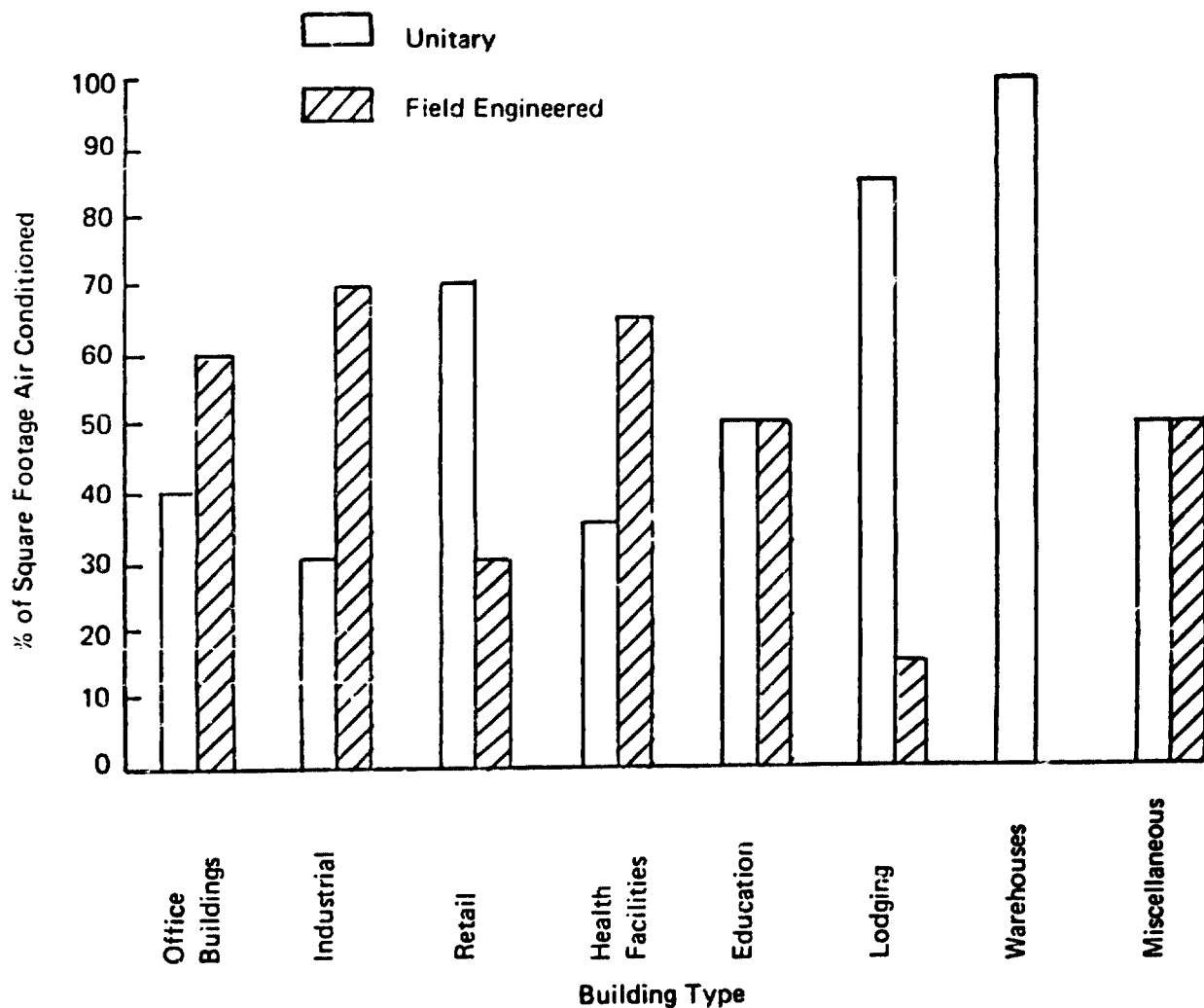


FIGURE 1

1980 FIELD-ENGINEERED/UNITARY SPLIT BY END USE

Source: Arthur D. Little, Inc., estimates.

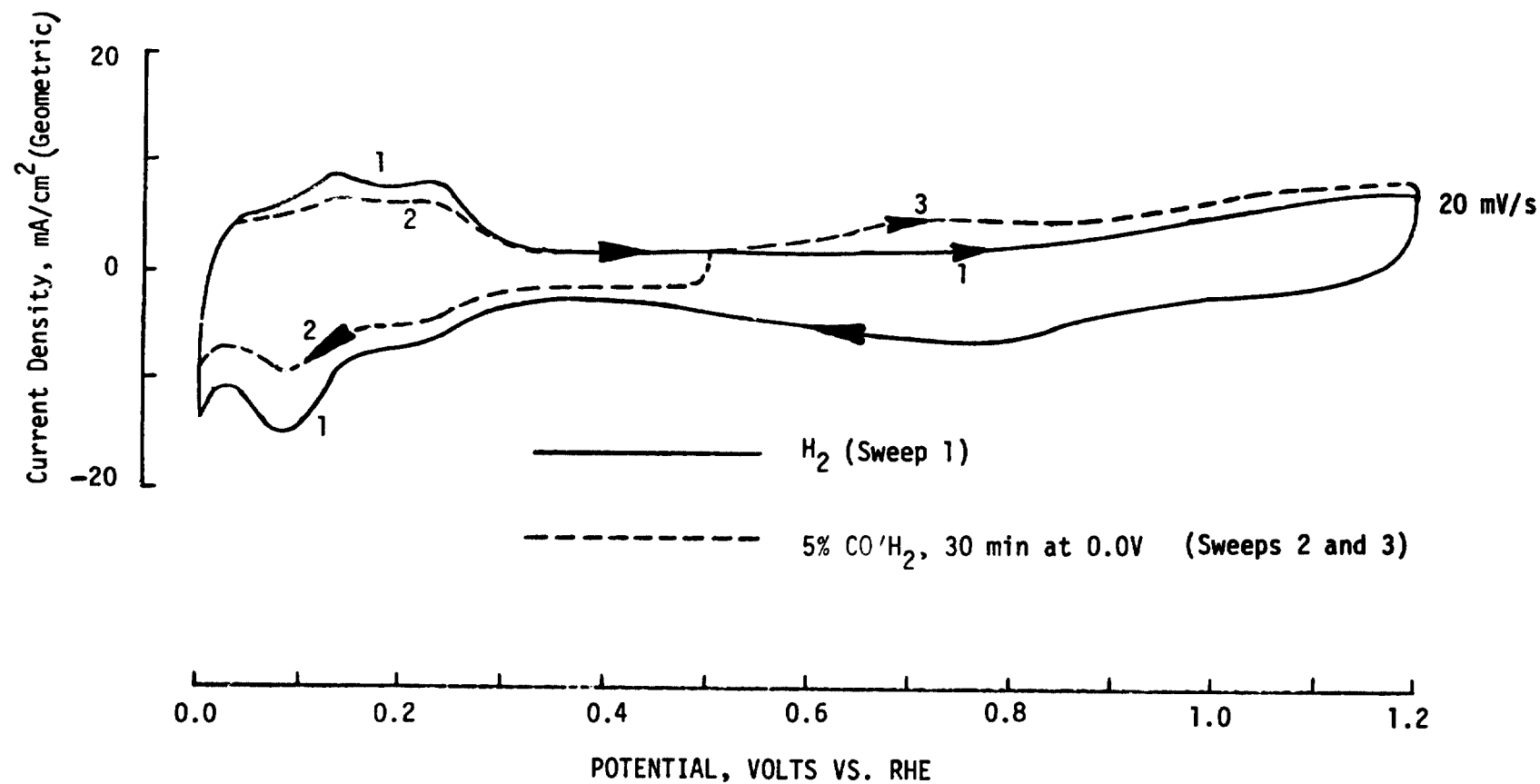


FIGURE 2 Voltammograms for 10% Pt on Carbon Electrocatalyst in 25% H<sub>3</sub>PO<sub>4</sub> at 25°C

ORIGINAL PAGE IS  
OF POOR QUALITY

ORIGINAL PAGE IS  
OF POOR QUALITY

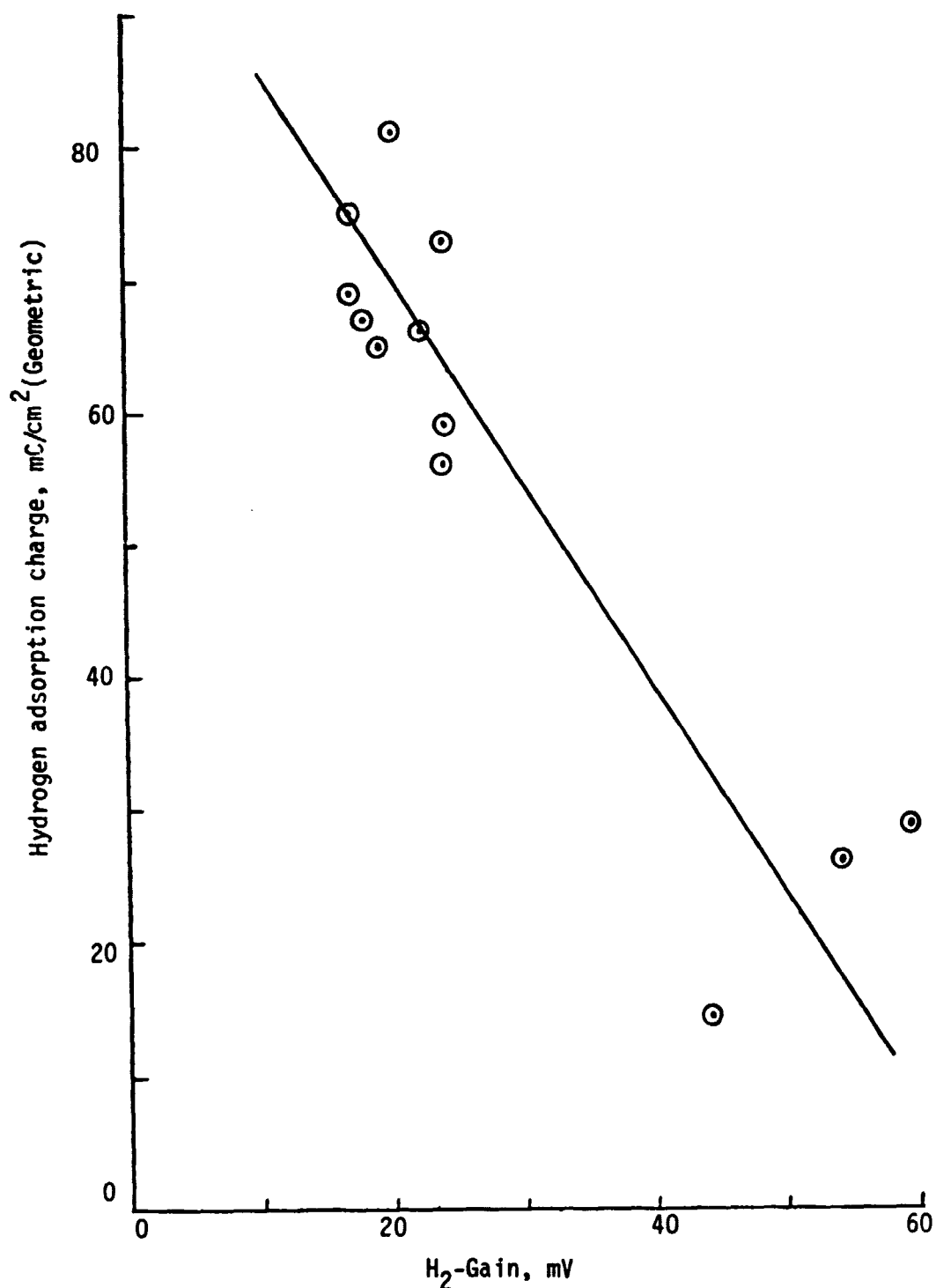


FIGURE 3 H<sub>2</sub>-Gain (190°C, 150 mA/cm<sup>2</sup>, 70% H<sub>2</sub> Utilization) vs. Hydrogen Adsorption Charge (25°C, 5% CO/H<sub>2</sub>) for 10% Pt on Carbon Electrocatalysts

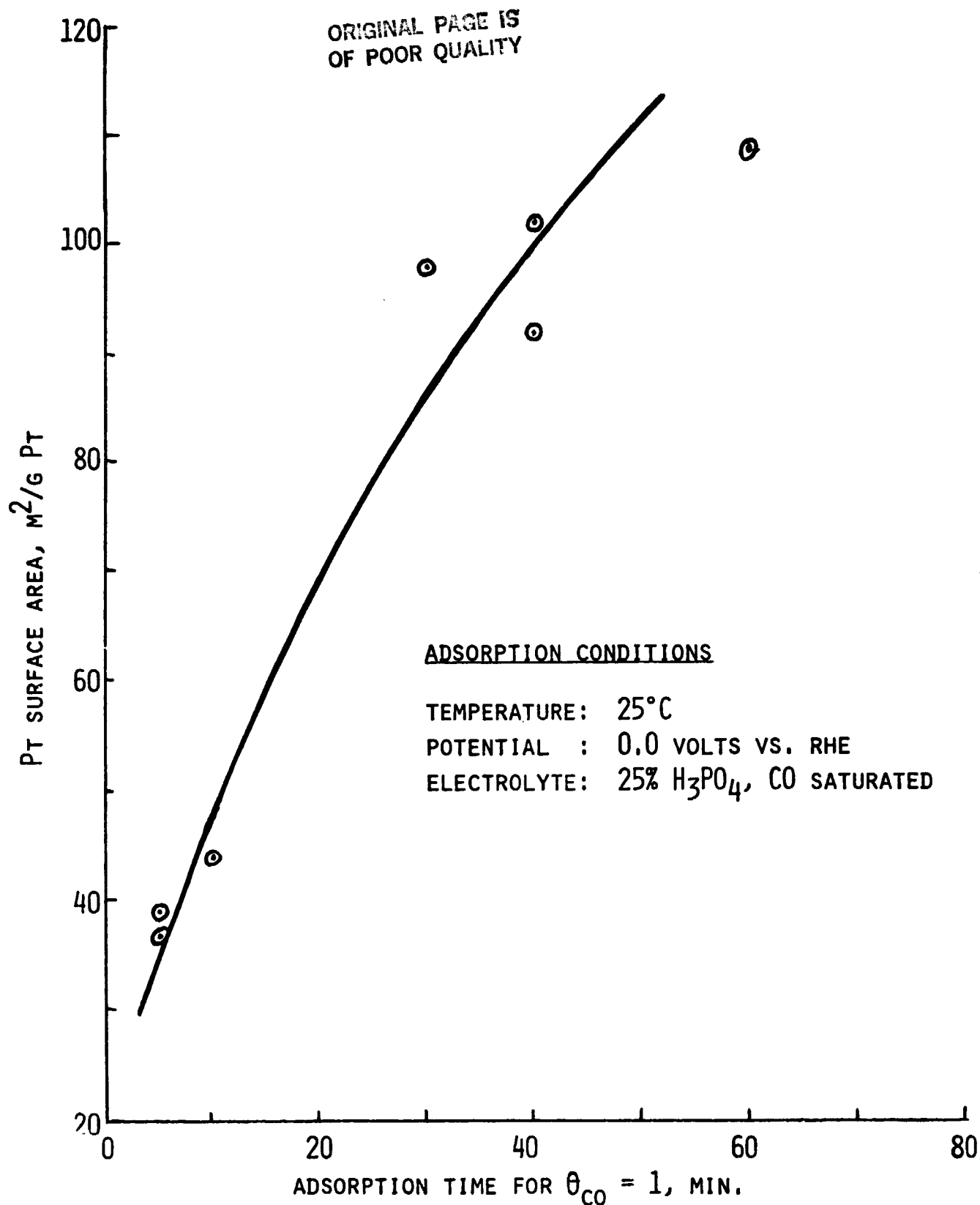


FIGURE 4

PLATINUM SURFACE AREAS OF SEVERAL CATALYSTS VERSUS  
TIME REQUIRED FOR COMPLETE COVERAGE BY CARBON MONOXIDE

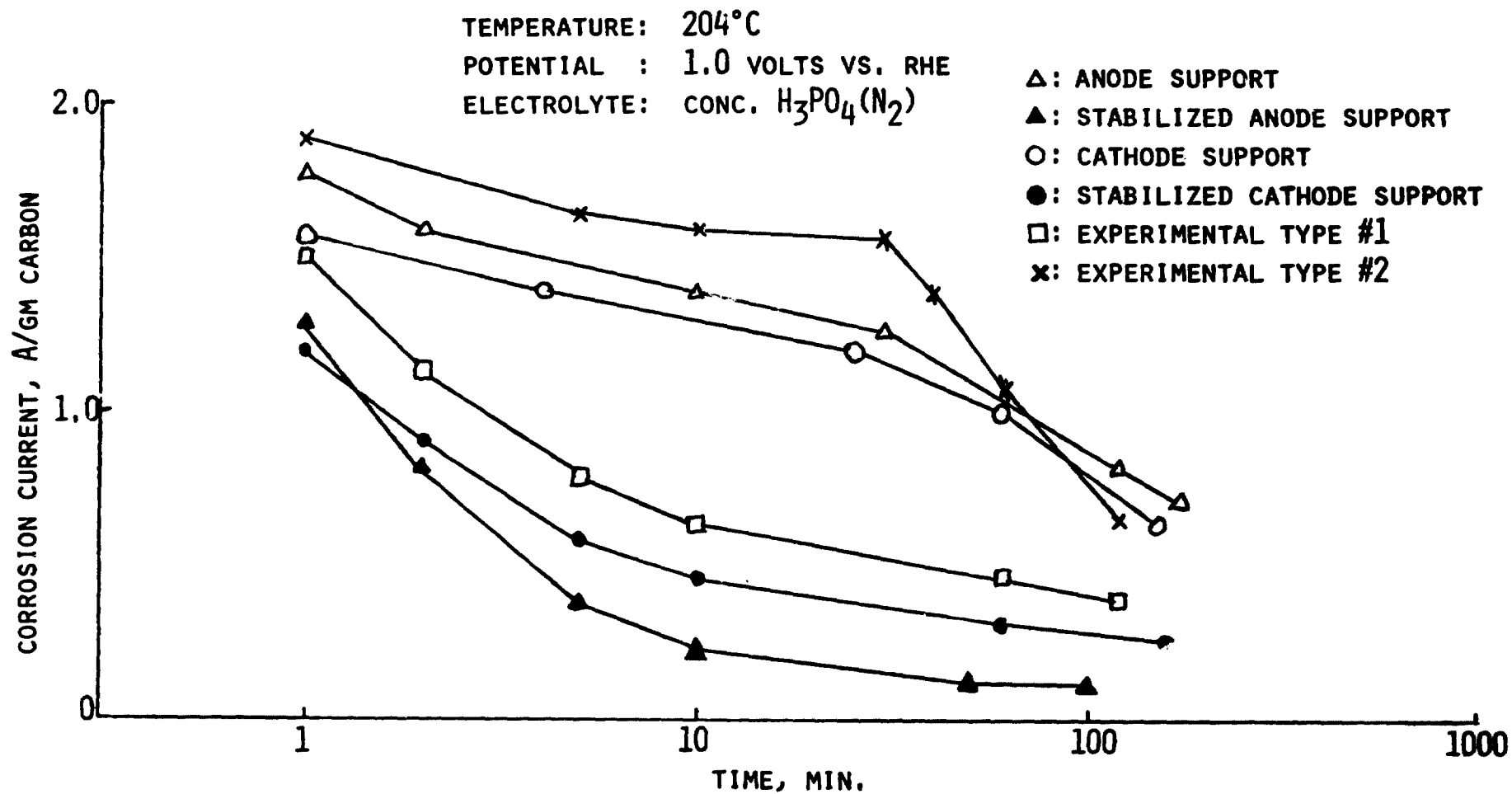
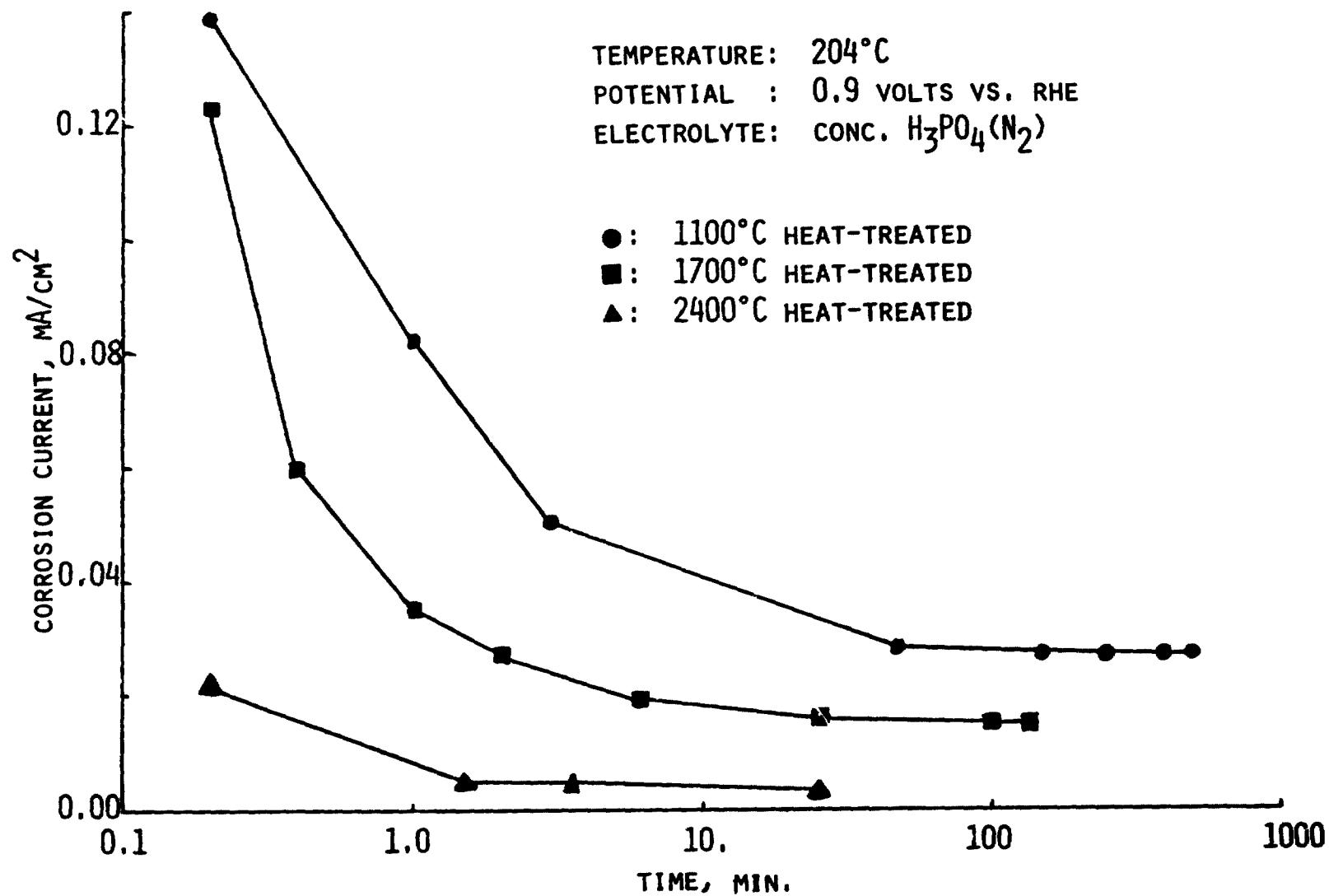


FIGURE 5 CORROSION CURRENTS OF CARBON SUPPORTS

3/5/82

ORIGINAL PAGE IS  
OF POOR QUALITY





ORIGINAL PAGE IS  
OF POOR QUALITY

FIGURE 6

CORROSION CURRENTS OF GRAPHITE ADHESIVE

ORIGINAL PAGE IS  
OF POOR QUALITY

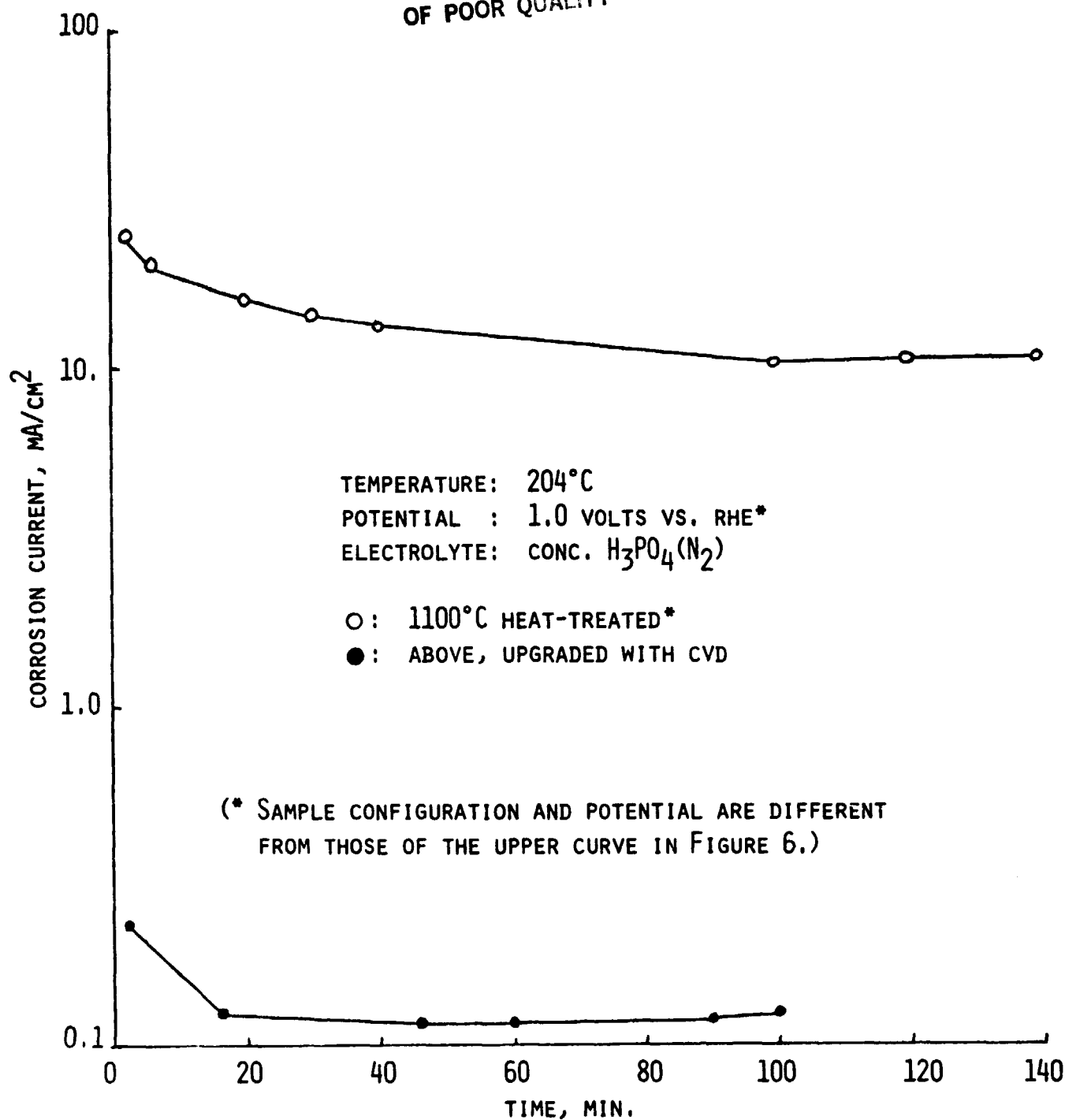
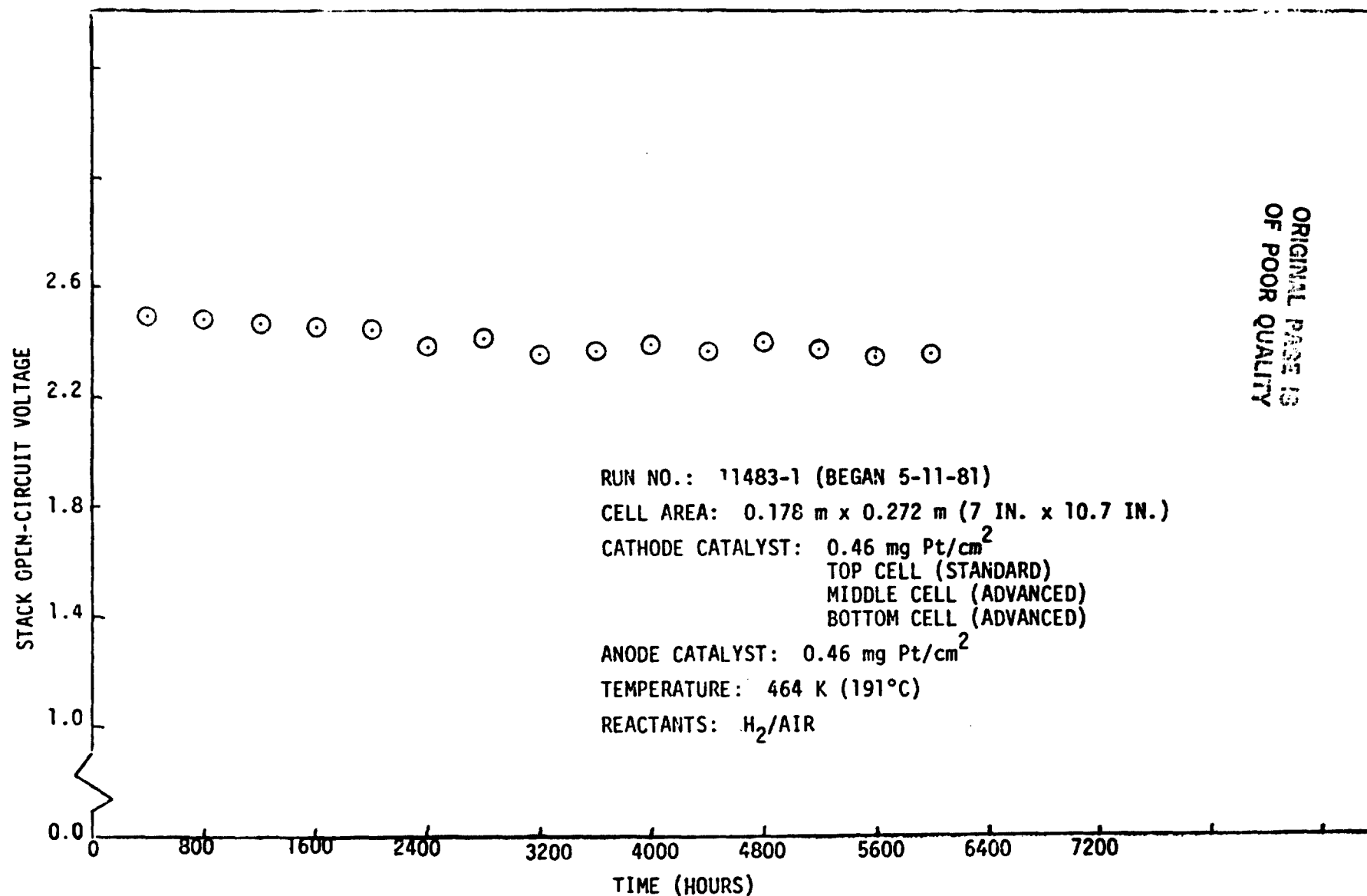


FIGURE 7 CORROSION CURRENTS OF GRAPHITE ADHESIVE



**FIGURE 8**

OPEN-CIRCUIT VOLTAGE STABILITY OF 3-CELL STACK

- ADVANCED CATALYST
- SEMI-AUTOMATED ELECTROLYTE-MANAGEMENT SYSTEM

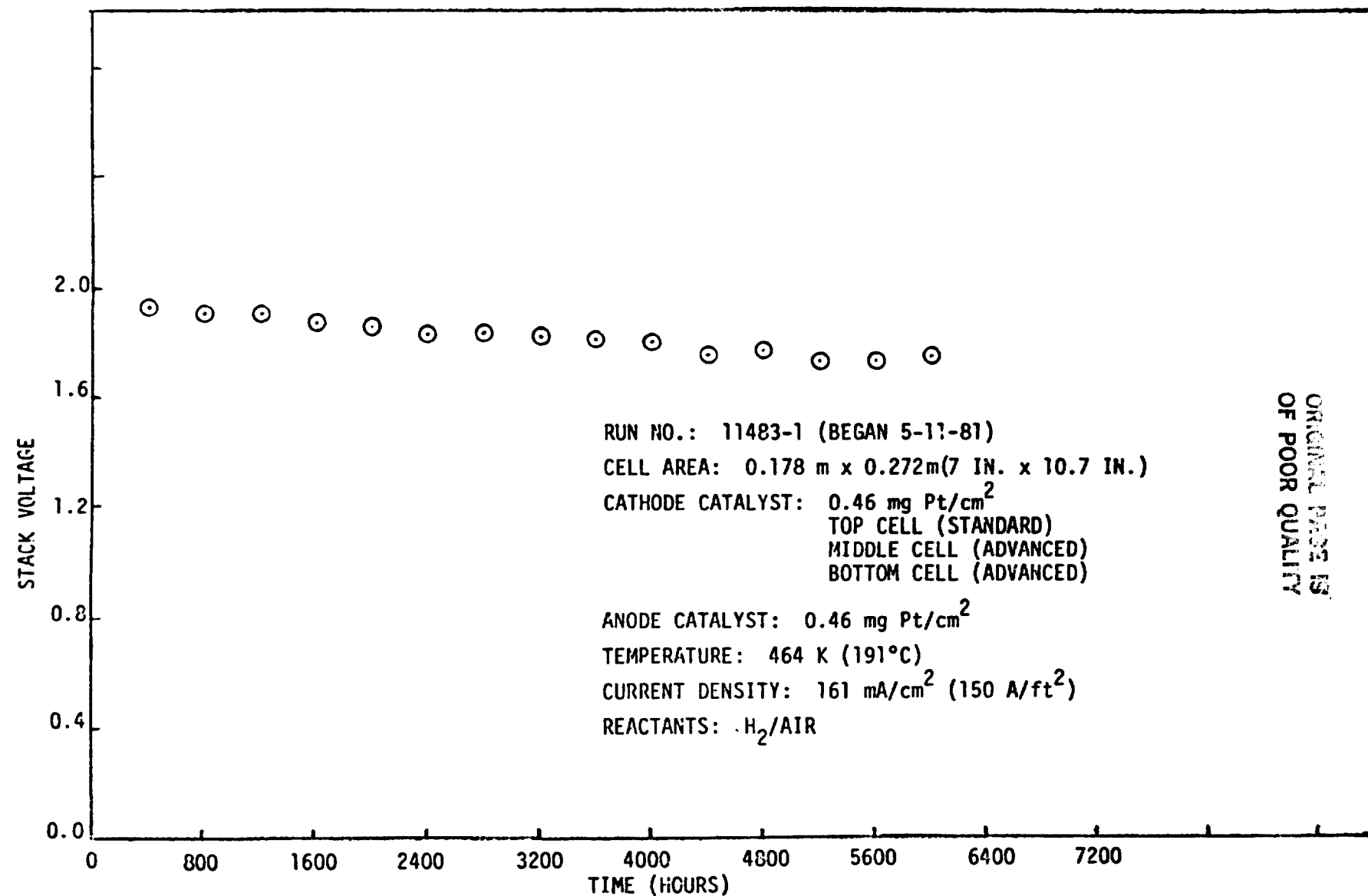


FIGURE 9 VOLTAGE STABILITY OF 3-CELL STACK

- ADVANCED CATALYST
- SEMI-AUTOMATED ELECTROLYTE-MANAGEMENT SYSTEM

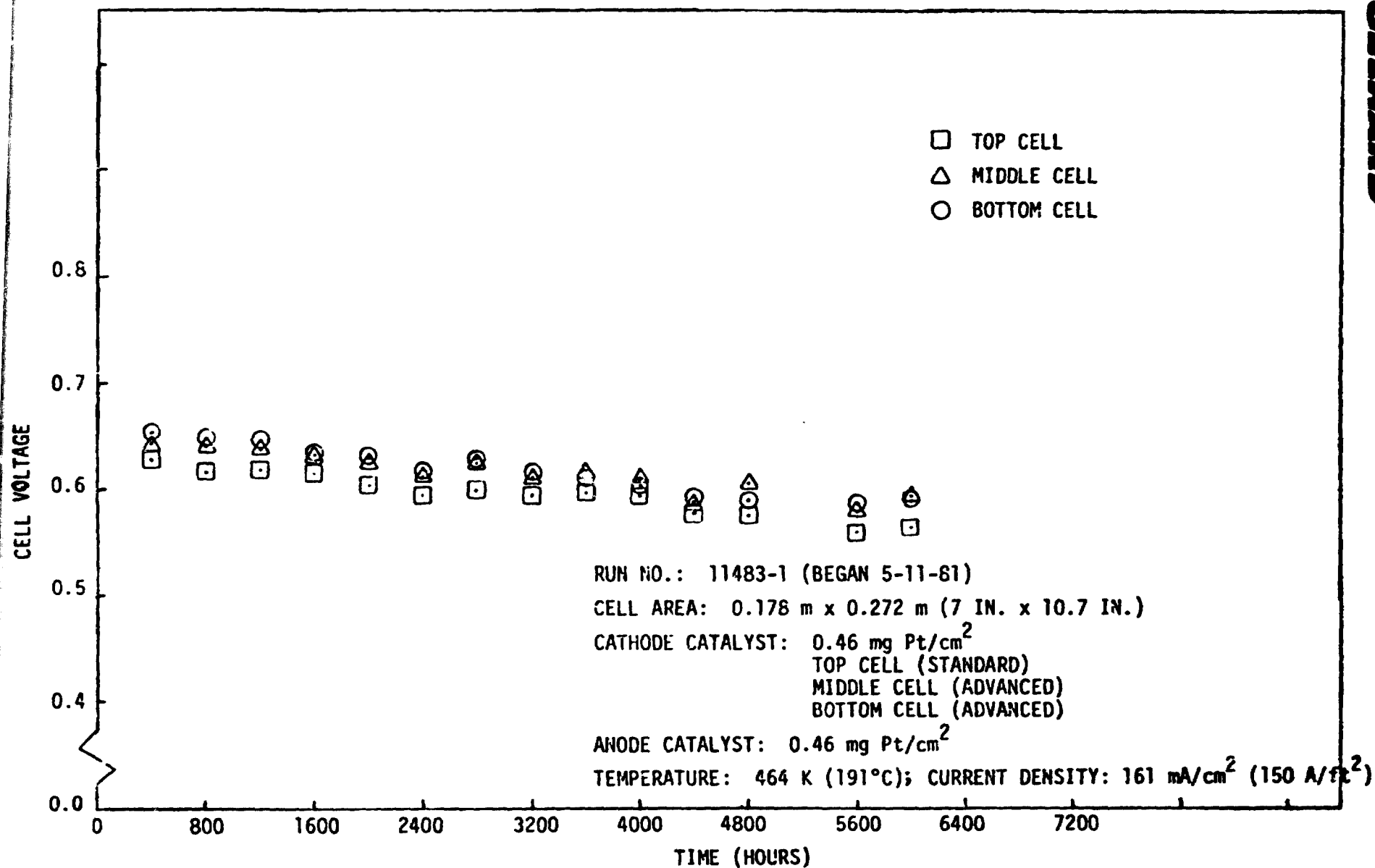


FIGURE 10 INDIVIDUAL CELL VOLTAGE STABILITY OF 3-CELL STACK

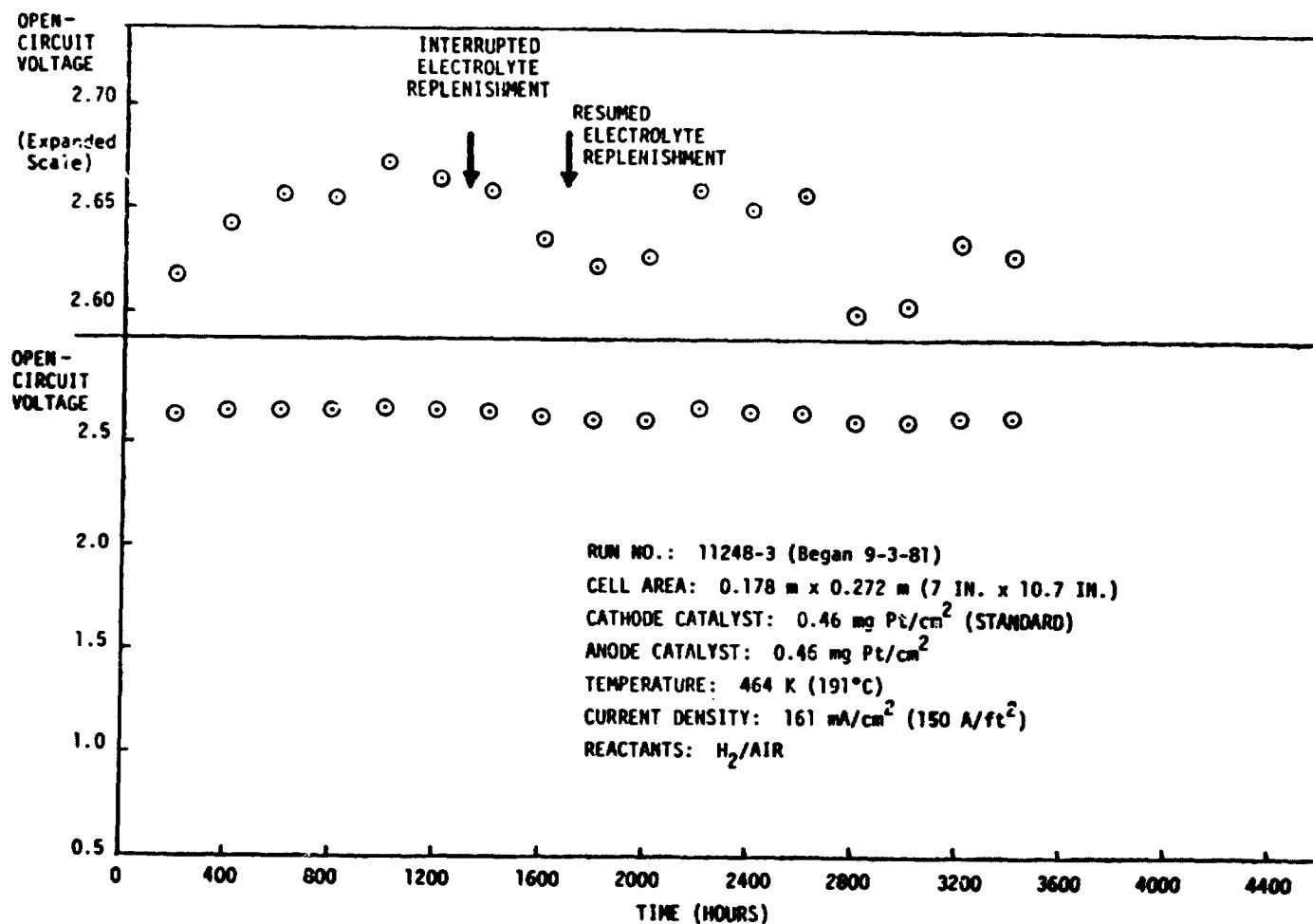
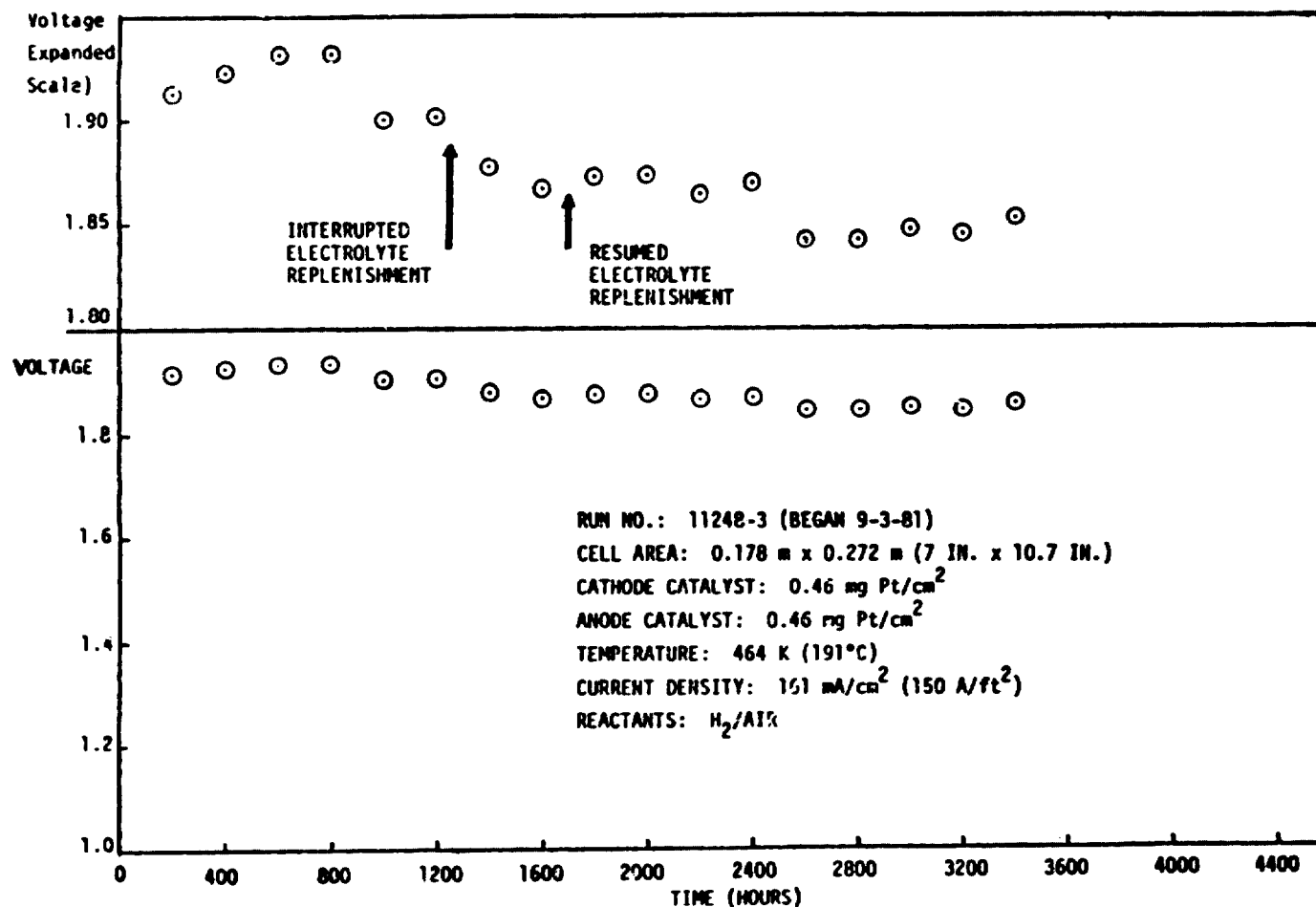


FIGURE 11 OPEN-CIRCUIT STABILITY OF 3-CELL STACK UTILIZING ADVANCED ELECTROLYTE REPLENISHMENT SYSTEM



**FIGURE 12** PERFORMANCE STABILITY OF 3-CELL STACK UTILIZING ADVANCED ELECTROLYTE REPLENISHMENT SYSTEM

PER CENT METHANOL CONVERSION

100  
90  
80  
70  
60  
50  
40  
30  
20  
10  
0

640

✓

1.1

670

✓

2.5

TEMPERATURE, K

800 PPM ETHANOL

% CO

CATALYST: ZN-Cr OXIDE  
C70-2RS

WHSV = 0.6 Gm MeOH/Gm Cat./hr.

1000

2000

3000

TIME ON STREAM, HRS.

FIGURE 13

SUMMARY OF TEST OF C70-2RS CATALYST

J. A. WHELAN 1-28-82



METHANOL CONVERSION, %

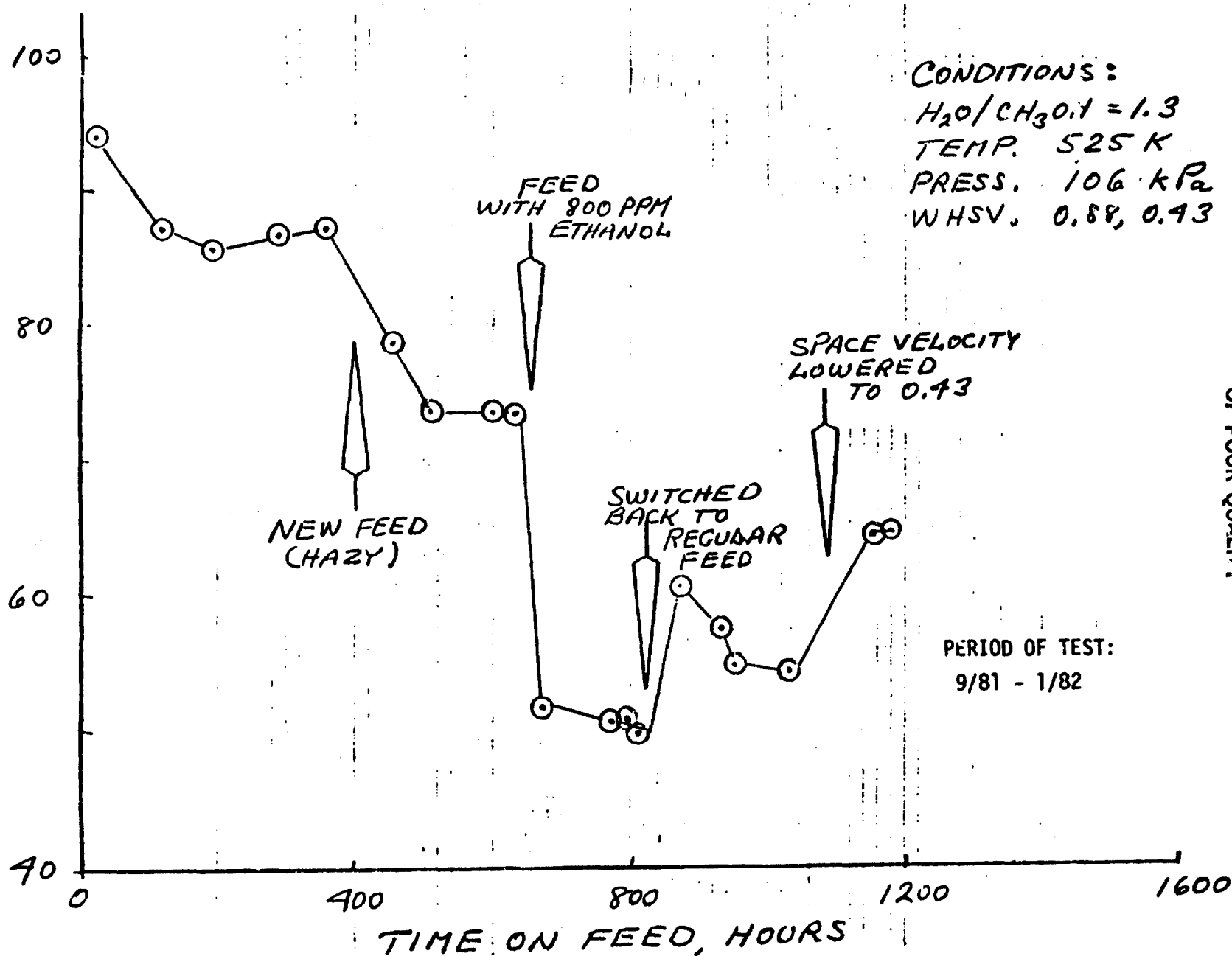
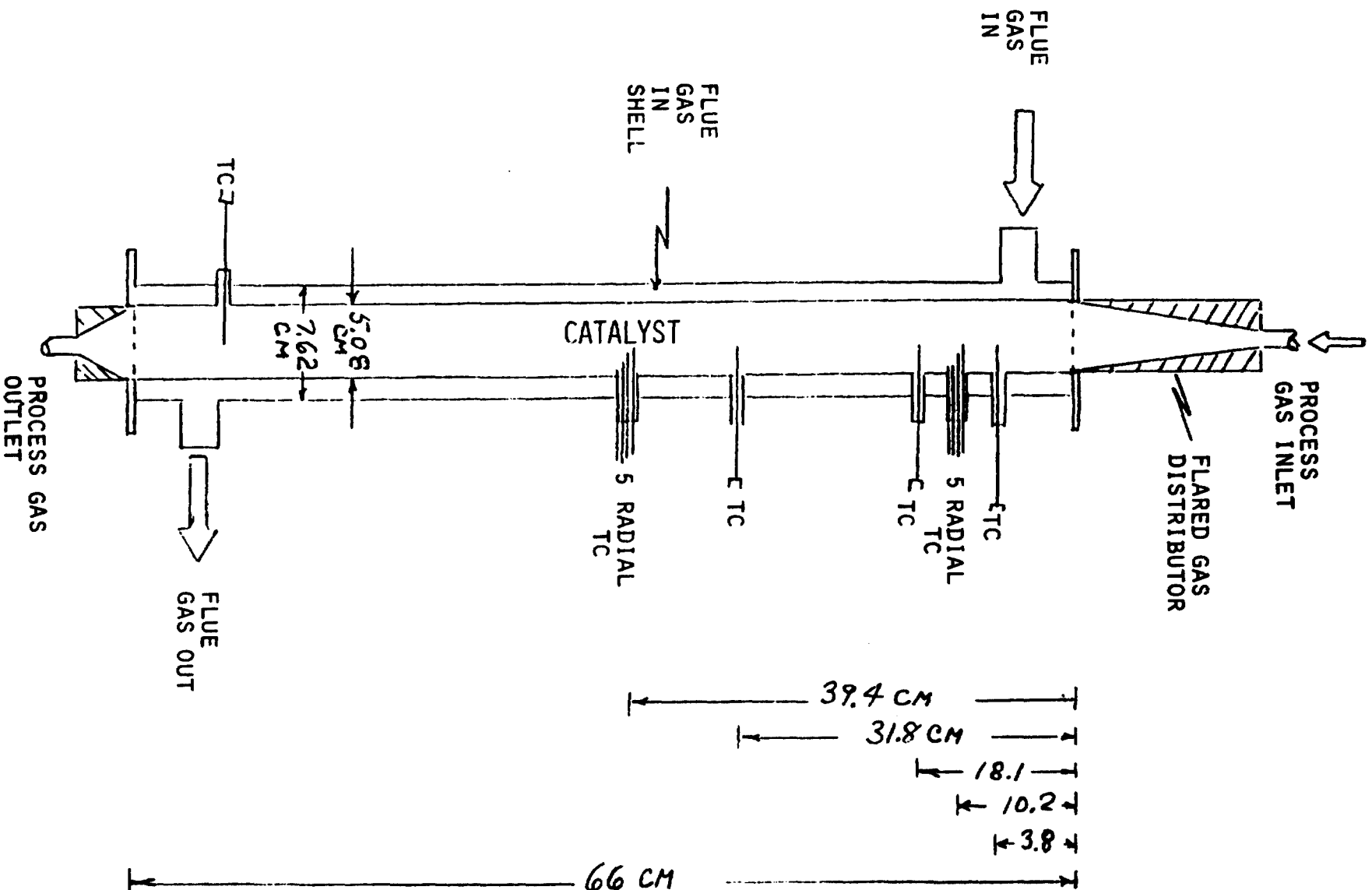
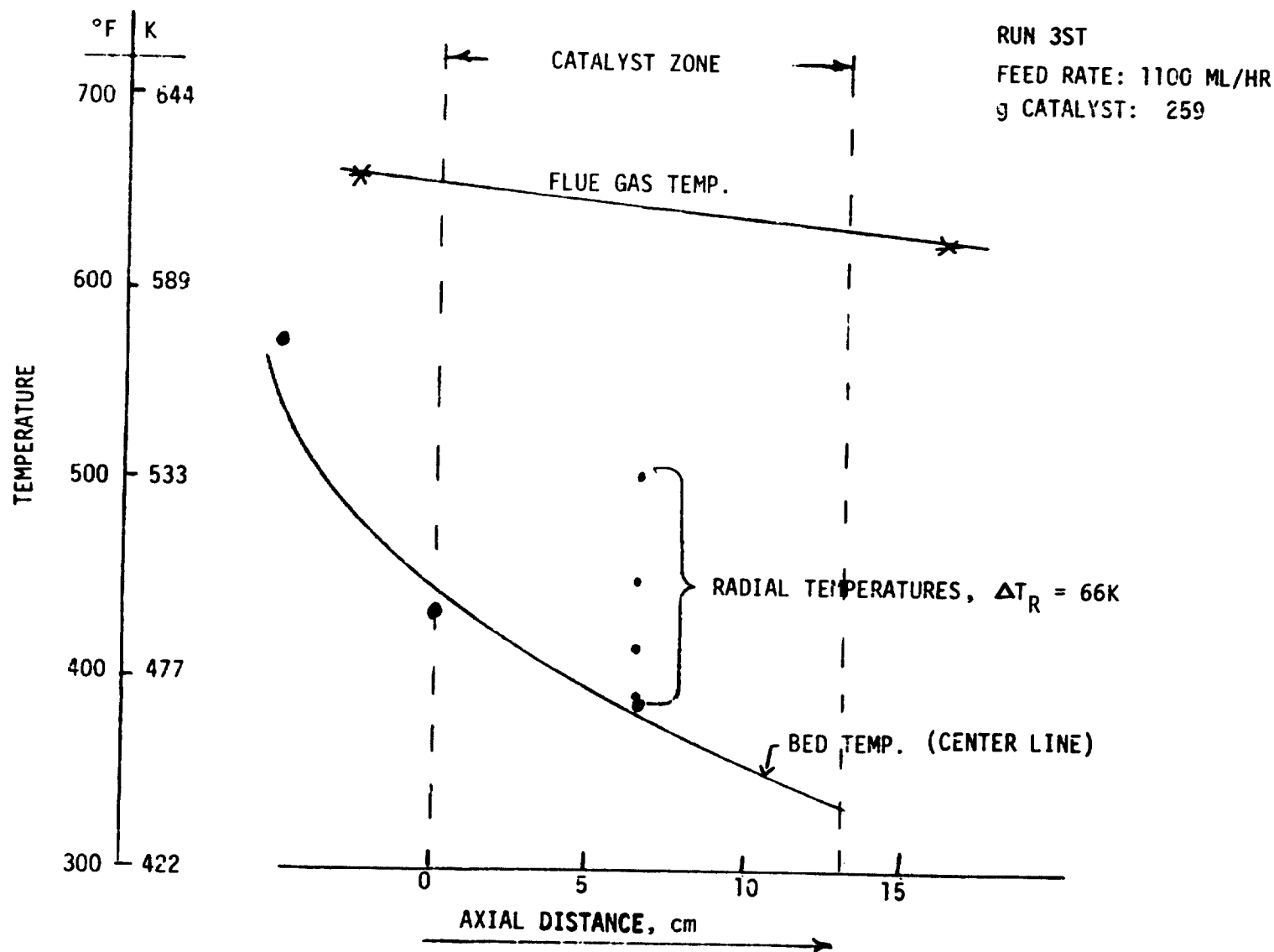


FIGURE 14

AGING STUDY WITH T2107 RS 1/8" CATALYST



**FIGURE 15** REACTOR FOR SINGLE-TUBE STUDIES



**FIGURE 16**      **TEMPERATURE PROFILES: 50mm D. TUBE**

12/3/81

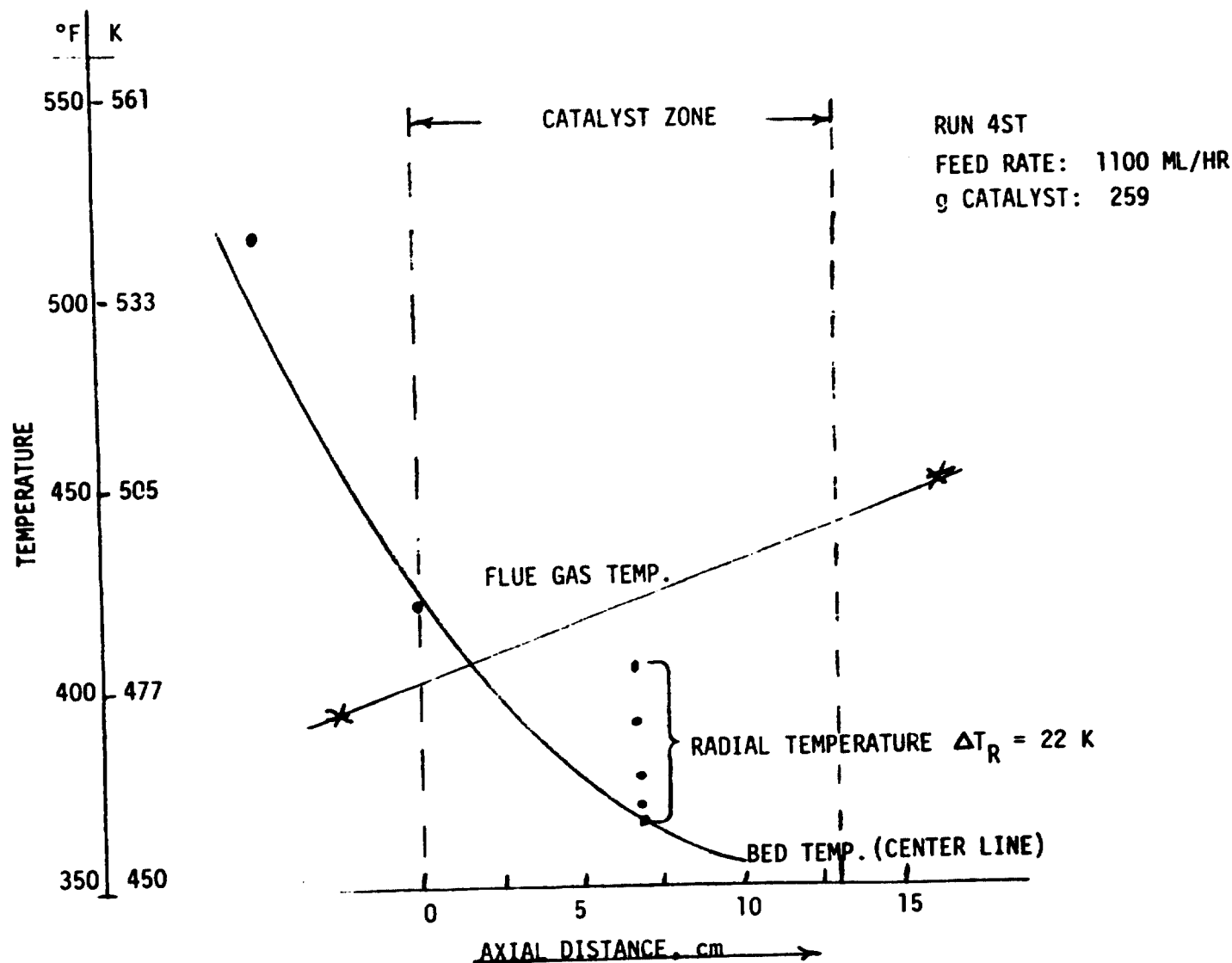


FIGURE 17 TEMPERATURE PROFILES: 50mm D. TUBE

12/3/81

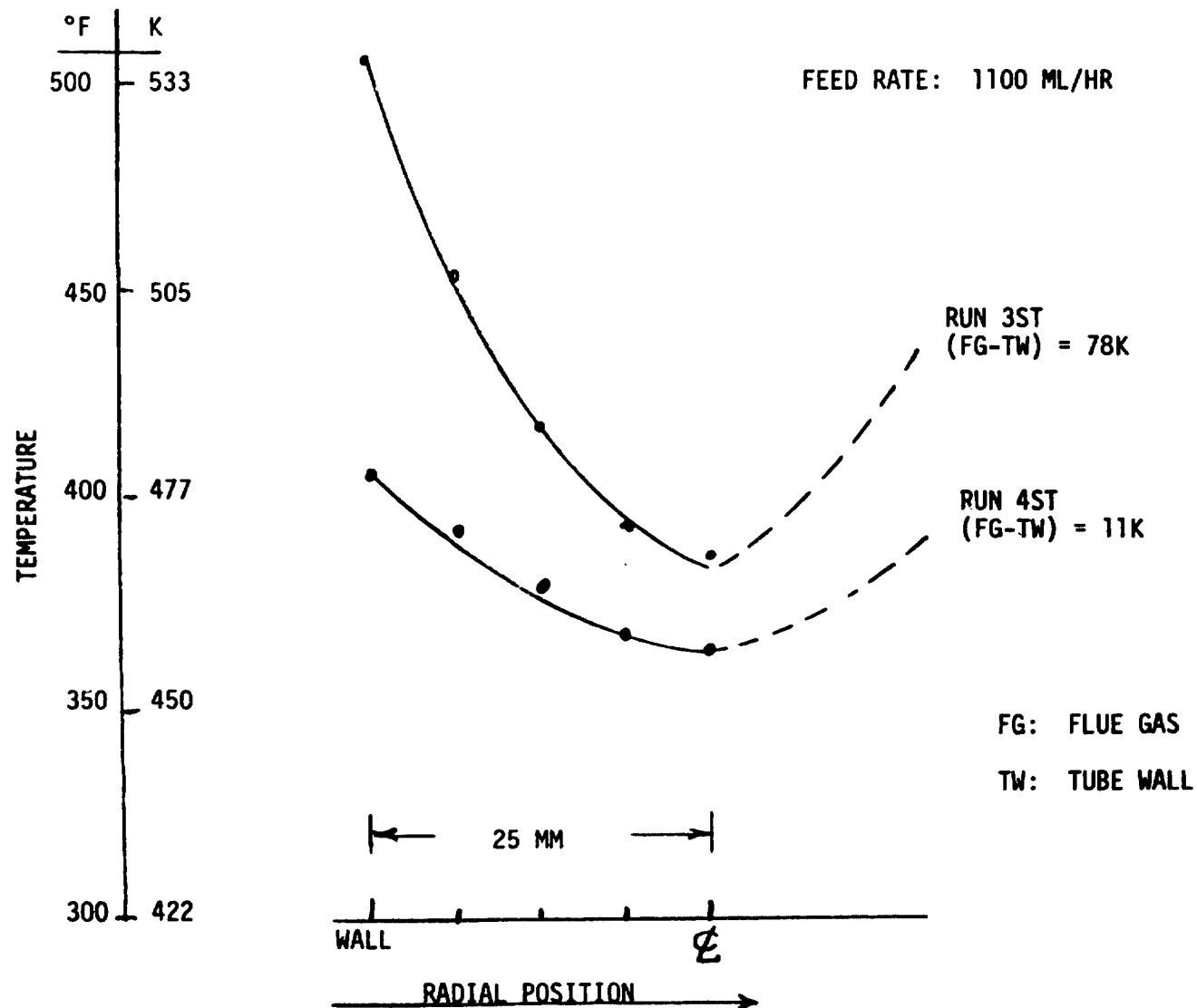


FIGURE 18 RADIAL TEMPERATURE PROFILES: 50 mm. D. TUBE

12/3/81